CONTRACT REPORT NO. OSQ84-00125

FINAL REPORT

Report No. PP-PSEF-85-48

O.R.F. Contract No. 40-10308

Flash Hydropyrolysis of Canadian Coals

D.S.S. Contract #15SQ.23440-4-9115

for

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July 30, 1985

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Executive Summary

Twenty one runs were made with Forestburg coal of which twelve tests were used to establish elemental and material balances. Some of the twelve were duplicate tests and parameters such as temperature and pressures were varied in others. No successful runs were made with Prince Mine bituminous coal although valuable data were gathered.

Hydrocarbon production (liquid and gaseous) increased with increasing gas temperatures. The gas temperatures were lower than external reactor wall temperatures which were accurately set and controlled. The gas temperatures depended on (a) the hydrogen preheat which in some cases could not be set as high as required because of the risk of bursting the preheat pipe; (b) the hydrogen/coal ratio; the cooling effect of the cold coal becomes significant at ratios below 1; (c) exothermic heat due to the oxidation of hydrogen and carbon by the oxygen in the coal.

The combined effect of these parameters defined the residence time at high (reaction) temperatures. When the high temperature processes were carried out quickly then a high liquid hydrocarbon production was obtained.

Mechanically the procedure of the process was improved in both the feed and colletion end. A new coal feeder was installed which operated very satisfactorily. The gas chromatograph was commissioned and operated well with an eight minute turn-around on the exhaust gas. The change in collection procedure resulted in an improvement in the mass and carbon balances from an average of 94% at the end of the previous campaign to better than 99% at the end of this campaign.

Taking the average of runs 47, 58 and 50 the conversion of the principal elements (carbon, hydrogen, oxygen) was as follows:

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1. Supply - Expressed as % MAF coal.

Source	Carbon	Hydrogen	Oxygen	Total
From coal	69.7	4.8	23.7	98.2
From hydrogen feed		4.7		4.7
Total	69.7	9.5	23.7	102.9

2. Conversion - Expressed as % of Supply

Products	Carbon	Hydrogen	Oxygen
Organic liquids	20.4	11.2	0.2
Gaseous hydrocarbons	22.9	52.1	
CO & CO_2 (Predominantly CO)	5.7		21.7
Char	51.0	13.9	8.2
Water		22.8	69.9

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1. INTRODUCTION

In the Flash Hydropyrolysis (FHP) process finely ground coal is heated rapidly to reaction temperature by preheated hydrogen and heated reactor. After a very short time at this temperature the products are rapidly quenched. The objective is the direct conversion into liquid and gaseous hydrocarbons, although normally other organic liquids, gaseous carbon oxides, char and water are also produced.

The schematic layout of the CANMET reactor at ORF is shown in Fig. 1. The coal hopper and a screw feeder are mounted above the reactor. The reactor itself is a 3.26 cm I.D. x 366 cm pipe (1 1/4" Sch. 80 x 12 ft.). The hydrogen is supplied from high pressure cylinders, preheated by an electrical resistance heater and ducted to the top of the reactor.

The gases with the entrained coal proceed in the downward direction through the reactor. The residence time of the gases is a function of the density (i.e. pressure and temperature) and feed rate. The denser coal particles fall faster than the gas, hence their residence time is shorter. The residence time also depends on the particle size.

There are four identical and separately controlled clam shell furnaces around the upper part of the reactor, while the bottom 90 cm (3 ft.) is left bare for quenching. The pipe terminates in a char trap. The products pass through a water cooled condenser, then a trap for the heavier organic liquids and water. Downstream of this is a liquid nitrogen cooled condenser and trap for the lighter organic liquids. Further down the gas stream is sampled for the Gas Chromatograph, then it is discarded.

The installation has a storage capacity to feed 1200 g of coal and about 1100 g hydrogen per test. The maximum rate is about 1600 g/hr. for each of the constituents. The most obvious faults were eliminated during the "Commissioning" tests in January - December, 1983. Eleven runs were made, of which five were "valid" i.e. provided an adequate body of data for a mass balance of acceptable accuracy. "Forestburg" sub-bituminous Western-Canadian coal was used.

The next series of tests in February - March, 1984 is called "Campaign 1". "Prince Mine" bituminous Eastern-Canadian coal was used for three of the fifteen tests, but caking problems and "hang-up" in the hopper compromised the data and it was not possible to provide a mass balance. Admixture of coarse clean sand in one case and hydrated lime in an other case did not help.

The rest of the runs were with Forestburg coal. Two of them were aborted with equipment failure and ten were valid. One of the tasks was to establish the effect of the reactor pressure in the 6.9 - 12.1 mPa (1000 - 1750 psi) range on the liquid hydrocarbon production. The conversion results have definitely improved with increasing pressure.

The second task was to investigate the effect of the temperature. Since the installation has a maximum safe temperature and the "Commissioning" results indicated that low temperatures are ineffective, the runs (excepting one at 650°C) were made in the relatively narrow range of 725 - 800°C. The third task concerned the effect of the residence time, which was adjusted through the regulation of the hydrogen rate. This, for the most common particle size, ranged between 5 and 9 seconds in the heated length of the reactor.

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The results indicated that the maximum residence times promote the formation of gaseous hydrocarbons. The generally accepted explanation is that the liquids are formed first and - if the quenching is delayed - some of them are converted further into gaseous products. Apart from this, the effects of these two parameters could not be established unequivocally. One of the reasons was the interaction between the parameters. For example: The coal is heated from ambient to reaction temperature primarily by the hydrogen, hence changes in the hydrogen rate affect not only the residence time, but also the temperature history of the coal.

The other important factor was the mass balance. In the early tests the unaccounted mass of the feed (coal and hydrogen) was 8-11% of the dry coal. With improved procedures this was reduced to an average of 5.4% for the final four tests. Further, the indication was that the missing mass represented primarily liquid products. The spread in this factor made the comparison of the test data difficult.

The operation of the FHP installation was virtually trouble free and the hydrocarbon conversion efficiency compared favourably with those of similar units elsewhere.

2. SUMMARY

Campaign 2 was the continuation of Campaign 1 with essentially the same tasks: To obtain maximum liquid hydrocarbon yields through the manipulation of the pressures, temperatures and residence times. The same two Canadian coals were to be used.

CANMET authorized the acquisition of a Gas Chromatograph. With this the data on the gaseous products become available within minutes as opposed to the one day delay earlier.

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A new coal feeder (Fig. 2) was designed and fabricated. It was installed atop a 60 cm (2 ft.) spacer pipe, hence the intrusion of hot gases into the hopper section was greatly reduced. The axis of the auger was vertical as opposed to the horizontal one of the original feeder. While this feature caused some considerable problems at the beginning, it eliminated the "hang-up" with the bituminous coal mixes. Further, it had a higher coal feed rate, thus all 1200 g coal in the hopper could be utilized during each test vs. only 440 - 900 g during Campaign 1.

The Prince Mine coal was mixed with dolomite, both constituents being in the same size range. Two runs were made with different temperature settings and mix ratios. In both cases, caked mix eventually formed a solid plug in the reactor. The starting points for the build-up were at different locations, but in both cases were in the zones where the temperature of the mix was expected to be in-between those in the hopper (ambient) and in the reactor (about 700°C). This problem could not be solved with the means then available, thus the tests with bituminous coal were discontinued.

Twenty-one runs were made with Forestburg coal. Two of these were at 13.8 MPa (2000 psi), the rest at 12.4 MPa (1800 psi) pressure. At the beginning the shut-off procedures were the same as those at the end of Campaign 1: The system was purged with hydrogen; partially depressurized; purged with helium, then sealed for an approximately 16 hours cooling period.

The analysis of the data indicated that the "unaccounted" masses were essentially constant in g/test unit, i.e. the rate or the aggregate mass of the feed did not make a significant difference. It was assumed that liquids have evaporated from trap of the first condenser; the vapours migrated into the still hot reactor space and condensed on the walls during the subsequent cooling period.

For the final tests the procedures were changed. During the low pressure purging the liquids in the traps were frozen with dry ice. Further, the traps were cooled again (with water ice) before opening. The improvements in the mass balance were quite dramatic. This can be seen in Table 1, where the best four tests from the two campaigns are compared. The differences in char and gaseous products can be attributed to the lower ash content of the coal (8.9 vs. 12.0%) and to the higher pressures (1800 and 2000 psi vs. 1750 psi) during Campaign 2.

The rapid heating of the coal from ambient to reaction temperature is an essential part of the FHP process. The most expeditious method for this is the direct heat transfer from the pre-heated hydrogen, hence hydrogen inlet temperatures should be, ideally, at least as high as those of the reactor.

The temperature of the pre-heater pipe must be higher than that of the gas, thus its mechanical strength is rather low. Seven per cent of all tests with this pre-heater were terminated with burst pipe. The spring loaded thermocouples did not give an accurate indications of the actual pipe temperatures, hence this crucial data was guessed from the setting of the electronic control. The heating power should change with the square of this, but the hydrogen rate/temperature/setting data in Table 13 shows very large and unpredictable discrepancies. For reasons of safety only the 700 - 775°C part of the reactor temperature task could be executed. Further, for the final tests with the best procedures 750°C represented the safe limit. Reduced heat transfer through oxidation was suspected and a brand new preheater pipe was installed. This, contrary to expectation, gave even lower temperatures.

The rates of the hydrogen feed were kept as high as the capacity of the supply cylinders and the cooling performance of the condensers allowed. This gave the shortest residence time: 7 seconds for the final tests.

3. CONCLUSIONS

3.1 Forestburg Sub-bituminous Western Canadian Coal

3.1.1 The test procedures and measurement techniques were greatly improved in the course of Campaign 2. All three tests with the full benefit of these (#47, 48, 50) had better than 99% mass and carbon balances. It follows that the performance of this installation can be assessed quite accurately.

3.1.2 The rest of the good tests did not have these excellent mass balances. Most of the "missing" liquid mass, however, was water, hence valid comparisons can be made on the basis of carbon balances.

3.1.3 The good tests were run at high hydrogen rates, hence the residence times were minimal. A significant reduction, however, is still possible through the alteration of the reactor assembly (Paragraph 4.3, following).

3.1.4 The two runs with 2000 psi pressure converted over 22% of the carbon into organic liquids vs. about 20% of the good 1800 psi runs, thus the high pressures were found to be beneficial.

3.1.5 The effect of the temperatures is not as clear cut as this. In the top part of the reactor these were affected by the furnace settings, the hydrogen preheat temperatures and hydrogen to coal ratios (on account of the cooling effect of the coal). Further, downstream the process heat increased the gas temperatures. (The coal contained 21% oxygen. About 70% of this was converted to water and about 20% to CO.). Even with this process heat the actual gas temperatures were probably lower than those set for the reactor. For example, with 750°C indicated reactor temperatures 625 - 650°C gas temperatures were measured directly below the lowest furnace.

Depending on the intensity of the reaction the quenching could be rapid or gradual. The relevant parameters are discussed in Appendix 1. It appears, however, that

(a) The combined carbon conversion into organic liquids and gaseous hydrocarbons increased with the temperature.

(b) In addition to this, the conversion into organic liquids depended on the rapidity of quenching.

3.2 Prince Mine Bituminous Eastern Canadian Coal

This coal, mixed with dolomite, was sucessfully fed. Liquid and gaseous hydrocarbons were produced. The accumulation of caked coal gradually plugged the reactor, hence the problem of feeding was not solved.

4. RECOMMENDATIONS

4.1 Ontario Research Foundation conducted an extensive literature survey on the FHP process, which was financed from its internal funds.

According to the information, the feeding of bituminous coals can be accomplished with the admixture of 15 - 30% very fine silica flour or other materials. Assistance from mechanical devices might or might not be essential.

The detailed recommendations for tests with Eastern Canadian coals were incorporated into ORF proposal P.4888-G, and were submitted to CANMET in June, 1985.

4.2 It appears from the literature that the residence time in the heated zone should be reduced more significantly than is possible with the control of the gas flow. To this end it is recommended that one or more of the four individual clam shell furnaces be removed and that the bottom end of the reactor should be cooled with water bearing coils.

4.3 For the setting of high hydrogen temperatures with some safety it would be highly desirable to measure the pre-heater pipe temperatures with optical thermometers and read the results in the control room. This, however, might be too expensive.

As a minimum requirement the values of the actual heating current and voltage should be displayed in the control room.

4.4 For the heating of the coal a coal/hydrogen ratio of 1:1 appears to be preferable. The capacity of the three hydrogen cylinders is not sufficient, hence the extension of the manifold for four cylinders is recommended.

4.5 The present auger in the feeder supplied the coal at about 1600 g/hr. rate and the clam shell furnaces in the high positions could not always maintain the set temperatures. In these cases the heating of the coal was not rapid, but gradual.

Since some of the furnaces may be removed, it will be necessary to test and install new augers for lower feed rates.

4.6 At the present the gas temperatures within the reactor are read only below the heated zone. It is desirable and possible to install thermocouples in the higher locations as well.

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5. EQUIPMENT AND PROCEDURES

5.1 General

This subject has been covered by the report of Kilborn Limited after commissioning and by ORF report # PP-PSEF-84-07 after Campaign 1. The emphasis in the following is on the improvements and problems during Campaign 2.

5.2 Coal Feed

The original feeder (Kilborn dwg. #100-43-007) was acceptable for Forestburg coal, although only 480-600 g/hr. rates were obtained. It was not, however, well suited for the mixes required with the Prince Mine coal:

(a) It was mounted directly atop the reactor and hot gases penetrated into the hopper-feeder motor compartment. It could not be cooled effectively.

(b) The axis of the auger was horizontal, thus a considerable force was exerted against the mix. The resulting friction sometimes led to uneven feeds (with occasional stops in the motor shaft) or to complete hang-ups.

A new feeder was designed, fabricated and installed (Fig. 2). The hopper was kept well above the reactor by a 610 mm (24") long spacer pipe. Further, some cold hydrogen was fed to the top of the hopper, thus the downward flow of this minimized the intrusion of hot gases. The water jacket ensured an effective cooling.

The auger was driven by a new and stronger motor; 10 RPM with 127 cm-N (11.25 in-lb.) torque vs 8 RPM with 51 cm-N (4.5 in-lb.). The axis of the auger was vertical, but initially the original size (Fig. 3) was retained.

The first five tests with this assembly were flawed by very low feed rates. (All changes with the feeder were routinely pre-checked with open reactor. The results, however, never gave true representations of the performances during the actual tests.) After these tests a larger auger (Fig. 3) was introduced. This worked well with Prince Mine coal, but on the first occasion with Forestburg coal the hopper emptied spontaneously before the start of the feeder motor.

With some experimentation a positive locking device was designed and installed. With this the discharge end of the hopper was completely closed until the start of the feeder motor. One-half turn of the motor shaft aligned two pins with two holes and a spring opened the discharge.

The finely ground coal was desiccated and sampled for moisture immediately before loading into the hopper. A second sample was taken from the coal left in the hopper after the test. In the first five runs the moisture content was typically 4 - 6% at start and about 1% less in the left over coal. This indicates migration, hence the feed contained as much as 9 - 11% H_2O. This was the probable cause of the low feed rates.

Subsequent tests started with much lower moisture contents, which - in addition to the larger auger - gave higher feed rates. The final tests started with essentially dry coal and the hopper was emptied on each occasion.

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5.3 Hydrogen Feed and Preheat

Three hydrogen cylinders with an actual volume of 100.25 L were connected to a common manifold. The pressure was displayed in the control room and timed readings were taken at frequent intervals. From these, with consideration of the equilibrium temperature in the storage shed, the interim and cumulative rates were continuously calculated during the runs.

A small part of the flow was ducted into the coal hopper, while the rest passed through the preheater. The hydrogen exit temperature was measured downstream of the high temperature electrical junction. This junction had to be left bare, hence the gas temperatures dropped between the heated section and this thermocouple. The net heat transfer into the hydrogen was calculated from the flowrate and temperature gain.

Considering the heat loss from the pipe and junction surfaces, good efficiencies were expected from the runs with high flowrates and relatively low exit temperatures. The test results, however, were not consistent. This prompted an investigation of the preheater performance.

On two occasions the heating currents and voltages were measured prior to the tests. It was learned that while the control settings are labelled by the manufacturer as "% power", in fact the voltage is controlled, hence the heating power increases with the square of the settings. On those occasions the highest setting actually measured was 75% and it gave 172.6 V, 74.6 A i.e. 12.9 KVA. This extrapolates to 22.8 KVA at 100%, which agrees well with the 24 KVA catalog data.

It was assumed that the tested "setting vs. heating power" function was the same for all runs and the heating efficiencies were calculated (Table 13). These ranged from 6% at 2500 g/hr and 650°C to 49% at 1260 g/hr and 700°C. While the results were not consistent, one pattern did emerge: New pipes started at high efficiencies, then gradually deteriorated. This can be explained with the oxidization of the pipe surfaces. At that time the desired high temperatures could not be obtained, thus a new pipe was installed for Test #45. The calculated efficiency was 48% at 1450 g/hr. and 772°C, but the drop of the performance was unusually rapid: 41% at the next test; 32-38% after that at essentially the same flowrates and only 740 - 760°C temperatures.

It can be assumed that in addition to the oxidizing effect the electrical resistance of the circuit changed slightly from test to test, hence identical settings did not give identical heating powers. Great care was taken to polish all surfaces at the junctions before each run, but the results could not be conveniently checked.

The problem was not that of the power (no more than 56% of the maximum was ever used), but the integrity of the pipe. At elevated temperatures even the Inconel material looses its strength quite rapidly. The "1000 hr. rupture strength", for example, is 68 mPa (9800 psi) at 850°C, but only 30 mPa (4300 psi) at 950°C. The 13.8 mPa (2000 psi) internal pressure imposes over 30 mPa (4300 psi) stress on the pipe. It follows that rupture was a very real hazard. Of the forty-six tests run with this pre-heater, the pipe ruptured on three occasions and was found bulged at another time. The data from tests with failed pipes was of little value and there was always an unplanned delay for the purchase of replacement pipe and to call a specialized welder with his equipment for the installation.

The pre-heater could be used to its limit if the pipe temperature could be read in the control room. The assembly, however, was moved by the heat expansion and the surfaces oxidized, hence the data from the spring loaded thermocouples were of little value (Table 13). Optical instruments with remote read-out were not available at ORF. The minimum requirement is the display of the actual heating powers in the control room, which eliminates the problems (if any) arising from the change in electrical resistances.

5.4 Reactor

There are four clam shell furnaces around the reactor, numbered from 1 on the top to 4 in the lowest position. Each of these has an independent control, which maintains the set wall temperatures very accurately with on/off cycling. However, at high coal rates and with inadequate preheat #1 furnace did not have enough power to maintain the set temperatures. Without preheated gas #2 was also similarly affected.

There are two spring loaded thermocouples between the furnaces in the #1/#2 and #3/#4 positions. The readings from these represented the outside wall temperatures. While the oxidation probably caused a constant error, the data were consistent. The hydrogen flow and the setting of the heaters remained constant from 5 minutes before to 10 minutes after the coal feed, hence the comparison of the before/after "hydrogen only" data to those obtained early/late during the coal feed is of some interest.

In the #1/#2 (high) position the wall temperatures increased by 9-16°C during the coal feed (Table 2). In the #3/#4 location the changes ranged from 1°C drop to 28°C rise and appeared to depend on the coal and hydrogen rates. The likelihood is that exothermic processes started on the top and their intensity and duration depended on the conditions.

The gas temperatures inside the reactor were measured only below the heated section: 610-665°C. In all runs but one, the gas temperatures increased by 35 - 54°C during the coal feed.

The residence time of the gas in the unheated reactor section was about 3 seconds. From here it entered the char trap, where the temperature dropped to 200/320°C (early/late during the test). With the planned removal of some of the clam shell furnaces the residence times in the unheated section will increase. For rapid quenching here the cooling of the walls seems to be highly desirable.

5.5 Condensers and Traps

The water cooled first condenser and its trap were installed to collect the water and the heavier organic liquids. In fact, in the Campaign 1 tests the bulk of the BTX was collected from this tarp. The Campaign 2 results were tested only for elemental balance, but the results were almost certainly similar (Table 7).

The data on the bottom part of Table 6 indicate that the "unaccounted" item in the mass balance meant primarily liquid products. Initially (#6 - 13 and #15) about 60 g/test was left unaccounted. With the introduction of the purge (hydrogen rates and temperatures were maintained for at least 10 minutes after the end of the coal feed) the liquids from the condenser walls were carried into the traps and only about 40 grams were unaccounted.

At test #46, after the regular purge, the hydrogen flow was maintained at low rates and with the heaters off. This method cooled the reactor to 340 - 420°C on the top and bottom, respectively. The flow prevented the migration of liquid vapours into the hot reactor space and only 20 grams were left unaccounted.

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From Test #47 onwards the right method was used: After the purge the reactor was cooled and was partially depressurized with low rates of hydrogen, then helium was switched in. When the conditions reached a safe level, then the reactor room was entered and dry ice was packed around the traps. The flow was maintained until the liquids froze. On the next day water ice was packed around the traps before the opening of the system.

With this method less than 10 grams were left unaccounted. The exception is Test #49. At that time the hydrogen was running out during the purge i.e. the pressure in the cylinders approached that in the reactor. In order to stretch the supply the pressure setting of the reactor was reduced with the hydrogen inlet valve still open. This, however, gave extremely high flowrates which probably carried some liquid vapours through the condensers.

The coal feed, in g/test units, is also listed in Table 6. It can be observed that while it ranged between 145 and 1200 grams, it had no discernible effect on the missing masses. However, the mass balances are normally expressed in "% dry coal" basis. In this respect the three tests with the best procedures and high coal feeds (#47, 48, 50) were outstandingly good: More than 99% of the feed was accounted for.

The liquids removed from the traps were weighed, then the water was separated in the ORF laboratories through the admixture of dichloromethane (CH_2Cl_2). The method is described in Appendix 2. The organic liquids were sent to an outside laboratory. Elementary analysis for C, H, N, S, O was performed for the products from both traps and for BTX and naphthalene for the products from the second trap. The data in Table 7 was generated from the laboratory report through chlorine balance. The sulphur content was given as "less than 0.3%" for all samples. In order to avoid guessing this element was not considered in the liquids, although the "Overall Balances by Elements" (Tables 4 and 5) suggest that these did contain some.

5.6 Gaseous Products

The volume of the system is 17.6 L, of which 6.9 L (coal feeder and spacer) is upstream of the reactor, 2.9 L is the reactor pipe and 7.8 L (product traps, condensers, piping) in downstream of the reactor. Since most of the product gases probably never enter the upstream space, the average gas elements, typically, pass through the reactor (including quenching section) in 0.5 minutes and through the downstream section in 4 minutes.

A CO analyser was installed and the readings were recorded in 15 second intervals in the critical periods and at one minute intervals under equilibrium conditions. The first indications normally appeared 4 minutes after the start of the coal feeder. Since there was a considerable mixing in the downstream space, the equilibrium value was reached about 3 minutes later. At the end of the feed the reverse process occured. The information from this instrument was used to synchronize the samples of the Gas Chromatograph (GC) with the feed.

Up to Test #33 gas samples were taken for subsequent analysis. After this the in-situ G.C. was commissioned. Samples could be taken and analyzed at 9-10 minute intervals. The results are shown in Tables 8 and 9.

5.7 Coal and Char

Two lots of Forestburg coal were used (Table 8). In the laboratory analysis the oxygen contents of these (and all coals, chars and liquids) were measured directly, rather than by difference. The sums of the elements did not necessarily add up to 100%. These are corrected for in the attached tables.

The coals were ground, sized and mixed for the runs as given in Table 12. Run #36 was incorrectly prepared on the account of a misunderstanding.

In the good runs of Campaign 1 about 50% of the coal was collected in the char trap. In Campaign 2 about 44% was the corresponding value. This, however, is largely the effect of the lower ash content in the coal. With the definition of

$$\text{Coal Conversion} = \left(1 - \frac{\text{MAF char}}{\text{MAF coal}}\right) \times 100$$

the typical data are 55 - 60% for Campaign 1 and 60 - 62% for Campaign 2.

All chars were tested for moisture right after the opening of the trap, but none was found.

6. TESTS WITH PRINCE MINE COAL

6.1 Background: Campaign 1

Only a small number of tests were run with this coal, thus it is useful to recapitulate and - in view of the better understanding at the present - to extend the information submitted in ORF Report PP PSEF 84-7.

Three tests were run in March, 1984. In all cases the original coal feeder (0.5 inch dia. auger with horizontal axis) was used. With similarly sized Forestburg coal this unit fed 480 - 680 g/hr. For reasons stated in the following the rate could not be established for the Prince Mine runs.

The test data is given in Table 10. The reactor temperature was normally uniform and steady at all four furnaces and for this reason only this common value is shown. The exceptions are discussed below. The reactor wall thermocouples were not installed for Campaign 1.

Four gas samples were collected at each tests, but the subsequent analysis did not indicate a measurable quantity of products. It is believed that Test #22 did produce gases for some time, but this probably occured between samples.

Test #21

During the preliminary bench test the coal could be fed at the normal rates, hence no additives were used. The regular test was uneventful. The subsequent inspection revealed that the reactor was plugged by hard, caked coal just above the entry of the hot hydrogen. At this location the hydrogen flow was unimpeded, but hardly any coal could enter the reaction zone, hence there were no solid or liquid products.

The hydrogen pre-heat thermocouple slipped from its mounting and the indications were falsely low. On the basis of the setting the temperature is estimated as 750 - 775°C.

Test #22

The hopper was charged with a 50 - 50 mixture (by weight) of coal and coarse clean sand. During the feed the current to the feeder motor fluctuated, indicating the grinding effect of the sand. The plug was found in the same location as at Test #21, but it apparently formed at a slower rate, since some char and liquid products were found in the traps.

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Test #24

Very fine hydrated lime (25% by weight) was mixed to the coal. The top clam-shell furnace was switched off so that the coal could have a chance to be entrained in the hot hydrogen before it attained coking temperature. Table 10 indicates, however, that this section was heated up by the hydrogen and by conduction from the lower elements.

While this coal-lime mixture was fed normally at the bench test, it hung up in the hopper during the regular run. This was probably caused by the hot hydrogen, which could freely circulate into the feeder region. There were no products.

6.2 Campaign 2 Tests in 1985

6.2.1 Preparations

Coal and dolomite were separately ground and sorted to the same size range (Table 12). The new coal feeder (0.73 inch dia. auger with vertical axis) was used. In bench test 2000 g/hr. feed rate was obtained.

6.2.2 Test #43

A 50 - 50 mixture (by weight) of coal and dolomite was used. The hydrogen pre-heater was switched off and the topmost reactor furnace was set to 550°C, the other three to 750°C. With these settings the coal was able to enter the reactor.

It can be seen from Table 10 that the two top furnaces could not compensate for the cooling effects of the hydrogen and coal, thus the temperatures dropped well below the set values.

The continuous CO monitoring indicated that the meaningful reaction lasted for approximately 20 minutes. The gas samples (Table 11) appear to indicate products well beyond this point, but this is the effect of the considerable dead volume (condensers and traps) in the system. The test was concluded after 60 minute feeding.

In the following inspection some coal was found in the hopper, but it fell into the char trap as the auger was disturbed. A cylindrical piece of coke, the same diameter as the reactor and 1.5 inch long, was found in the char trap. A plug started to build up from the low end of the #2 reactor section.

18 g of liquids was taken from the #1 condenser trap, 5.7 g from that of #2. This distribution is unusual, since with Forestburg coal only about 10% of the liquids pass through the #1 trap. Of the liquids, 7.5 g was organic and 16.2 g process water.

6.2.3 Test #45

20% coal was mixed with 80% dolomite. With the higher density of the dolomite 2000 g charge could be loaded into the hopper.

The pre-heater and all four reactor elements were set to 775°C and these remained essentially the same during the feed. The hydrogen rate was 1260 g/hr. in the first 18 minutes, then it increased to 1440 g/hr.

The gas analysis indicated a gradually diminishing feed rate. After 34 minutes of feed the ammeter of the motor indicated jamming and the test was concluded.

The after test inspection revealed that a plug, similar to that found after test #43, closed the reactor in the vicinity of the hydrogen inlet. This did not restrict the hydrogen flow.

The distribution of the liquids between the condensers was again unusual: 31.1 g from the first, 13.1 g from the second. Organic liquids totalled 5.25 g, the water 39.02 g.

6.2.4 Comparison of Gaseous Products (Table 11)

The gas production for the #1 readings is shown in g/hr. units. It is reasonable to assume that at these particular times the feed rates were at about 2000 g/hr. mix for both tests. With the different ratios this translates to:

Test #	Feed Rates, g/hr.		Product Gases, % Coal			
	Coal	Dolomite	Gaseous Hydrocarbons	CO	CO_2	All process gases
43	1000	1000	10.3	0.9	4.5	15.7
45	400	1600	23.2	43.6	15.6	82.4

While much of the oxygen and - probably - some of the carbon originated from the dolomite [Ca Mg $(CO_3)_2$], the more intensive reaction of the high temperature Test #45 is quite evident.

7. TESTS WITH FORESTBURG COAL

7.1 Class 1

It had been discussed earlier that the differences among the results can be attributed primarily to the test procedures (liquid collection techniques and mass of coal fed during the test). Accordingly the data are classified according to these.

The final twelve valid runs gave the best results and are considered as Class 1. The char and the liquid products were analyzed and the full evaluation is presented in the attached tables.

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Class 1a: 3 Runs - (#47, 48, 50)

The loss of liquids was greatly reduced by packing dry ice around the traps and simultaneously maintaining a low rate purge after the end of the runs. Carbon and mass balances were better than 99%.

On the debit side, 750°C or lower hydrogen preheat temperatures had to be accepted. The topmost clam shell furnace could not maintain 750°C.

Class 1b: 2 Runs - (#46, #49)

An interim collection technique was used for #46 (paragraph 5.5). For #49 the right collection technique was used, but the results were flawed by the extremely rapid decompression (paragraph 5.5). Both had the same problems with the preheater and #1 furnace as the Class 1a runs. The results, however, were still very good.

Class 1C: 5 runs - (#37, 38, 41, 42, 44)

These tests were run well, but the original liquid collection technique was used. However, 1200 g wet coal was fed at each time, hence the mass and carbon balances were 96% or better.

At Run #44 a 775°C hydrogen preheat temperature could be obtained, while the reactor was kept at only 725°C. The production of organic liquids was unusually high for the original collection technique: 14.5% of the dry coal (Table 2). These settings might have promoted the rapid heating/rapid quenching of the materials, which is known to be beneficial for liquid hydrocarbon production.

ORI

Class 1d: 2 Runs - (#35, 36)

These were similar to the Class 1c runs, but less coal was fed during the test, hence the mass balances were only 94%. Even these were slightly better than the seven Campaign 1 runs with purge and much better than the three runs without purge.

#35 was run with the large auger, but the new positive locking device had not been introduced at this point. Two washers were installed on the bottom of the auger. These prevented the free run-out of the coal, but restricted the feed rate.

For #36 the locking device was installed, but the incorrectly prepared very fine coal (Table 12) gave a very low feed rate. Further, an improper sealing material burned off from a flange connection and the hydrogen leak forced a premature, but orderly shut-off. There was no purge.

7.2 Class 2: 5 Runs - (#26, 27, 28, 29, 34)

These were the early runs with the new coal feeder and the feed rates were very low. Further, the CO analyser indicated that the rates were not uniform. The mass balances are shown on Table 6, page 2. It can be seen that the unaccounted masses in g/test units were normal (excepting #34, discussed below), but on % coal basis were as high as 13-21%. For this reason the costs of char and the liquid analyses were not justified.

For #26 the original, low torque motor was used in conjunction with a 12 mm (0.48") diameter coil type auger. The coal rate was quite low. For #27 the high torque motor became available and stirring elements were mounted on the shaft for higher feed rates. One of these elements, however, hooked into the electrical wire and the direction of the rotation alternated in 60° arc. Test #28 was run normally with the same set-up, while for #29 the machined auger of Campaign 1 replaced the coil.

For these tests the first lot of the coal was used, which had 12.3% ash vs. 8.9 of that in the second lot. In spite of this #29 had only 41% char. There is nothing in the test records that could explain this anomaly.

The feed rates could not be increased with the small diameter hopper discharge. It was enlarged for the large auger. This performed well on three consecutive tests with pitch (conducted for a separate contract), but failed during the first test (#33) with Forestburg coal: the hopper emptied spontaneously before the commencement of the hydrogen feed.

For #34 a washer was mounted on the bottom of the auger to prevent the free run out of the coal. Judging by the weight of the solids in the char trap, about 40% of the coal ran out before the start of the feeder. The tables are based on the before/after difference of the masses in the coal hopper, thus the gas and liquid production appears to be quite low.

The in-situ gas chromatograph was commissioned.

7.3 Failures: 4 Runs - (#25, 33, 39, 40)

#25 was the first test of Campaign 2. After 45 minute run the preheater burst. Coal and liquids were lost during the sudden decompression. Subsequently one-half of the preheater pipe, on the hot (discharge) end, was replaced with a clean surfaced pipe. Also, the original mild steel electrical junction on the high temperature end was replaced with smaller stainless steel piece.

#33 was the first Forestburg run with the new auger. As mentioned above, the coal run out prematurely.

The positive locking device was introduced and used successfully on three consecutive runs. At #39, however, the sideway thrust of the spring jammed the device, which did not open at all. For run #40 a new spring was installed, which was too weak to open the hopper. After this a third, intermediate strength, spring was installed and the problem was solved.

8. NOTES TO THE TABLES

Table 2

The preheater control was normally set to maintain a temperature. As the surroundings were gradually heated up, the heating power was automatically reduced. With high powers, however, it was safer to set the power and allow the rise of temperatures.

The reactor temperatures in the four heated zones were normally identical and remained constant. In the late runs, however, the top element could not maintain the set temperatures during the coal feed. As a compensation, for the last two runs this zone was raised above those of the others before the feed period. For clarity, in the table the spaces for alternate temperatures are filled out only when there were some changes.

In the reactor wall and gas discharge temperature sections the averages of the "hydrogen only" readings (first and fourth items) are compared to the averages of the two "coal feed" readings (second and third items). Normally there was a rise on account of exothermic processes.

The gas velocities and residence times were calculated from the volumetric rates of the gas flows and from the heated reactor length and volume. The particle velocities, relative to the gas, were calculated for 125 micron particles. Considering there was a range of sizes and that these sizes were reduced by the reactions, the residence times in the heated zone are approximations only. This question was discussed in some detail in the PP-PSEF-84-07 Campaign 1 report, paragraph 4.4 and 7.4

The mass balance section is expressed a "% dry coal". This is given in more detail in Table 3, but was included here for the quick comparison of the tests conditions and results. Conversely, the critical test data were re-stated in the mass and elemental balance tables.

Table 3

The Coal Conversion was defined in paragraph 5.7. Briefly, it assumes that all elements of the MAF coal not identified in the char were "converted". These are included for direct comparison with those in the Alberta Research Council report. [Flash Pyrolysis/Hydropyrolysis of Alberta Subbituminous coals: Design, Construction, Operation and Initial Results of a High Pressure 1-5 KG/Hour Bench Unit; S.K. Gangwal and J. Mendiuk; Coal Research Department, Alberta Research Council, Edmonton, Alberta, Canada; Report No. YCPY-8; November, 1983].

In the report on Campaign 1 ORF concluded, on the basis of elemental balances, that the masses left unaccounted are "liquids; predominantly water" (PP-PSEF-84-07, Paragraph 2.3). This assessment is confirmed in this table: as the "unaccounted" item was reduced, the liquids, particularly the process water, increased.

The formation of water contributed a considerable heat to the process. This was manifested by the temperature rises shown in Table 2. The oxygen was taken from the coal. In contrast, in the Rockwell International FHP process oxygen is injected into the hydrogen in a "pre-burner" for preheat. [Coal Conversion by Flash Hydropyrolysis and Hydrogasification. Oberg, Carl L.; Combs L., Paul; Silverman, Jacob. Rockwell Intl. Presented at the 13th Intersociety Energy Conversion Engineering Conf., San Diego, Aug. 20 -25, 78, Vi. P402 (7)].

Tables 4 and 5

While the masses of the coal, char and liquids were weighed, those of the gases were calculated from the hydrogen balance. Hydrogen was supplied at known rates directly and also from the coal. These were compared to the number of hydrogen atoms in 100 mole gas.

The accuracy of the data for the other elements depend not only on the test data, but also on the chemical analyses. Considering this, the agreements seem to be quite good.

The oxygen balances are of some interest. The first lot of coal contained 21.6% oxygen, that of the second lot 20.8%. About 70% of this was used for the formation of water, hence did not tie down any carbon. Of the rest, about 20% appeared as CO & CO_2 (mostly CO), and 10% was identified in the char.

Table 6

In this all valid "Forestburg" runs are presented in a uniform "% dry coal" basis. The water was not separated in the early runs, hence all liquids are grouped together.

This table was used to illustrate the various methods used to improve the mass balances.

Table 9

At the early runs the coal rates were quite low, hence long tests (sometimes over two hours) were the rule. This allowed the analyses of ten or more gas samples. In the final tests the hopper was emptied in about 45 minutes, hence only four "equilibrium" samples could be used.

In the table the spaces for CO_2 were left blank when none could be detected in the samples.

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Table 1: Mass and Carbon Balances of the Best Runs

TABLE 1a: Mass Balances in "% dry coal"

	* Camp. 1.	** Camp. 2	Difference
Organic Liquids	11.6	14.2	+ 2.6
Gaseous Hydrocarbons	17.7	18.4	+ 0.6
CO & CO_2 (primarily CO)	7.4	8.4	+ 1.0
Char	49.7	44.2	- 5.5
Process Water	11.9	17.7	+
Indentified	98.4	103.0	+ 4.6
This includes H_2 from the Gas Feed	4.2	3.9	- 0.3
Unaccounted	5.8	0.9	- 4.9

TABLE 1b: Carbon Balance

	** Camp 2
Organic Liquids	20.9%
Gaseous Hydrocarbons	22.1%
CO & CO_2 (primarily CO)	5.7%
Char	50.9%
Total	99.7%

* Average of tests #17, 19, 20, 23

** Average of tests #46, 47, 48, 50

TABLE 2: Test Data
Forestburg Coal

Test #		50	49	48	47	46	44	42	41	38	37	36	35
Date	month.day	3.28	3.26	3.22	3.20	3.18	3.12	3.06	3.02	2.22	2.20	2.18	2.11
Duration of test	min	48	44	41	47	51	56	51	45	75	69	43	148
Reactor pressure	psi	2000	2000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Reactor pressure	MPa	13.8	13.8	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
Hydrogen feed rate	g/h	1441	1532	1384	1206	1274	1292	1213	1069	1050	1037	938	596
Coal (dry) fed during test	g	1200	1200	1200	1200	1200	1196	1194	1196	1190	1181	355	903
Coal feed rate (dry)	g/h	1516	1636	1756	1548	1412	1276	1485	1395	952	1034	494	366
Pre-heater voltage setting	%	75	75	72	75	69	64	53	60	54	70	70	68
Hydr. preheat, start of feed	C	734	743	745	750	750	775	705	750	725	714	710	699
Hydr. preheat, end of feed	C	740	755	750	742			700			736		727
Reactor temperature set to:	C	750	750	750	750	750	725	700	750	725	775	775	750
B1 furn. at start of feed	C	761	761										
B1 furn. at end of feed	C	721	725	727	738	743							
Reactor wall B1/B2 before feed	C	570	569	573	557	555	491	518	495	451	475	476	450
Reactor wall B1/B2, early	C	584	579	581	563	564	500	525	509	463	485	489	463
Reactor wall B1/B2 end of feed	C	586	580	581	566	567	503	527	520	465	489	491	461
Reactor wall B1/B2 after feed	C	568	565	567	553	556	492	513	506	448	477	BB/A	456
Increase on account of feed	C	16	13	11	10	10	10	11	14	15	11	14	9
Reactor wall B3/B4 before feed	C	591	590	592	586	585	547	550	593	565	607	605	581
Reactor wall B3/B4, early	C	589	596	590	604	600	578	564	623	584	632	625	608
Reactor wall B3/B4 end of feed	C	571	574	576	590	588	574	564	617	580	629	620	603
Reactor wall B3/B4 after feed	C	571	574	575	584	578	568	552	592	565	610	BB/A	592
Increase on account of feed	C	-1	4	-1	12	13	9	10	28	17	22	22	19
Gas discharge, before feed	C	602	602	610	605	605	590	570	610	594	628	629	610
Gas discharge, early	C	640	640	640	650	640	626	610	657	630	665	655	621
Gas discharge, end of feed	C	644	647	643	650	650	633	620	667	640	685	660	630
Gas discharge, after feed	C	614	618	608	610	613	592	590	620	605	640	BB/A	624
Increase on account of feed	C	54	54	53	47	36	39	35	47	36	41	29	9
Gas velocity	cm/s	15	16	16	14	14	14	13	12	12	12	11	7
Particle velocity	cm/s	22	22	23	23	23	23	23	23	23	23	23	23
Gas residence time	s	19	18	17	20	19	19	21	23	24	23	25	41
Particle resid time	s	7	7	7	7	7	7	8	8	8	8	8	9
1st Condenser	% coal	30.8	29.3	29.1	26.4	30.3	28.9	26.7	28.1	27.4	27.5	25.5	25.3
2nd Condenser	% coal	2.8	2.9	2.9	3.1	2.5	2.1	1.6	2.3	2.9	3.0	4.5	3.9
less moisture from coal	% coal	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.7	2.7	4.6
Organic Liquids	% coal	15.1	15.3	14.4	12.8	14.6	14.5	12.4	13.8	13.0	13.2	14.2	12.8
Process water #	% coal	18.6	16.8	17.5	16.7	18.1	16.2	15.5	17.1	17.0	16.5	13.1	12.7
Gaseous hydrocarbons	% coal	19.6	17.8	18.3	19.4	16.2	16.2	15.5	17.8	17.3	21.4	19.6	21.7
CO & CO2	% coal	7.4	7.1	8.2	9.8	8.4	7.8	8.5	7.6	7.8	7.1	4.4	8.4
Char	% coal	42.9	42.9	45.2	44.9	44.0	45.3	47.8	45.5	45.4	44.1	47.7	44.4
ALL PRODUCTS #	% coal	103.6	100.0	103.6	103.6	101.4	100.1	99.8	101.8	100.4	102.3	99.0	99.3
FEED #	% coal	104.2	103.8	104.4	104.1	103.1	103.5	103.5	104.1	104.1	105.1	104.5	104.5
UNACCOUNTED	% coal	0.6	3.8	0.8	0.6	1.7	3.4	3.7	3.8	3.7	2.8	5.5	5.2
Unac'd for the whole test	%	7.6	45.5	9.9	6.6	20.3	41.2	44.4	36.2	43.5	33.0	19.4	47.8

The unreacted hydrogen and the moisture from the coal feed are not included.

TABLE 3: MASS BALANCES

Forestburg Coal

Test #		50	49	48	47	46	44	42	41	38	37	36	35
Reactor pressure	psi	2000	2000	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Reactor temperature	C	750	750	750	750	750	725	700	750	725	775	775	750
Hydrogen pre-heat temperature	C	740	750	750	755	750	775	700	750	725	730	710	720
Gas discharge temperature	C	660	665	660	655	650	630	620	660	635	680	655	630
Coal feed rate (dry)	g/h	1516	1636	1756	1548	1412	1276	1405	1595	952	1034	494	366
Hydrogen feed rate	g/h	1441	1532	1386	1206	1274	1292	1213	1069	1050	1037	938	596
Coal (dry) fed	g/test	1200	1200	1200	1200	1200	1196	1194	1196	1190	1181	355	903
Coal conversion, MAF basis	% coal	61.7	61.9	59.4	59.6	60.7	59.6	56.8	59.9	58.7	60.3	55.9	62.4
Hydrogen feed	% coal	95.1	93.6	78.9	77.9	90.2	101.3	86.3	67.0	110.3	100.3	109.8	162.9
Less hydrogen gas in effluents	% coal	90.9	89.8	74.5	73.7	87.2	97.8	82.9	63.0	106.2	95.2	105.3	158.4
Hydrogen added to products	% coal	4.2	3.8	4.4	4.1	3.1	3.5	3.5	4.1	4.1	5.1	4.5	4.5
Coal (dry)	% coal	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FEED #	% coal	104.2	103.8	104.4	104.1	103.1	103.5	103.5	104.1	104.1	105.1	104.5	104.5
Liquids from condensers	% coal	33.7	32.1	31.9	29.5	32.8	31.0	28.3	30.4	30.3	30.5	30.0	29.3
less moisture from coal feed	% coal	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.7	2.7	4.6
LIQUID PRODUCTS	% coal	33.7	32.1	31.9	29.5	32.8	30.7	28.0	30.0	30.0	29.7	27.3	24.8
Organic Liquids	% coal	15.1	15.3	14.4	12.8	14.6	14.5	12.4	13.0	13.0	13.2	14.2	12.0
Process water	% coal	18.6	16.8	17.5	16.7	18.1	16.2	15.5	17.1	17.0	16.5	13.1	12.7
Gaseous hydrocarbons	% coal	19.6	17.8	18.3	19.4	16.2	16.2	15.5	17.8	17.3	21.4	19.6	21.7
CO & CO2	% coal	7.4	7.1	8.2	9.8	8.4	7.8	8.5	7.4	7.8	7.1	4.4	8.4
GASEOUS PRODUCTS	% coal	27.0	25.0	26.5	29.2	24.6	24.0	23.9	25.5	25.1	28.5	24.1	30.1
CHAR	% coal	42.9	42.9	45.2	44.9	44.0	45.3	47.8	45.5	45.4	44.1	47.7	44.4
ALL PRODUCTS #	% coal	103.6	100.0	103.6	103.6	101.4	100.1	99.8	101.0	100.4	102.3	99.0	99.3
UNACCOUNTED	% coal	0.6	3.8	0.8	0.6	1.7	3.4	3.7	3.0	3.7	2.8	5.5	5.2

The unreacted hydrogen and the moisture from the coal feed are not included.

TABLE 4 : BALANCES BY ELEMENTS

Expressed as "% of the Element in Dry Coal".
Forestburg Coal

Test #		50	49	48	47	46	44	42	41	38	37	34	33
Reactor pressure	psi	2000	2000	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Reactor temperature	C	750	750	750	750	750	725	700	750	725	775	775	750
Hydrogen pre-heat temperature	C	740	750	750	755	750	775	700	750	725	730	710	720
Gas discharge temperature	C	660	665	660	655	650	630	620	660	635	680	655	630
Coal feed rate (dry)	g/h	1516	1636	1756	1548	1412	1276	1405	1595	952	1034	494	366
Hydrogen feed rate	g/h	1441	1532	1386	1206	1274	1292	1213	1069	1050	1037	938	596
Coal (dry) fed	g/test	1200	1200	1200	1200	1200	1196	1194	1196	1190	1181	335	903
C in organic liquids	% C	22.2	22.5	20.5	18.9	22.1	20.8	17.4	18.5	19.4	19.8	21.3	17.0
C in gaseous HC's	% C	23.6	21.4	22.1	23.4	19.5	19.5	18.6	21.4	21.6	26.5	24.3	27.0
C in CO & CO2	% C	5.0	4.8	5.5	6.6	5.6	5.2	5.6	5.2	5.4	5.0	3.1	5.9
C in char	% C	49.2	48.7	52.0	52.4	50.1	51.4	54.8	50.9	52.4	50.3	53.4	47.4
Carbon identified	% C	100.0	97.5	100.1	101.2	97.3	97.0	96.5	96.0	98.7	101.6	102.1	97.3
H in organic liquids	% H	18.7	21.2	30.1	17.7	8.9	22.2	23.3	24.6	20.6	22.8	23.4	19.6
H in gaseous HC's	% H	105.0	96.9	98.6	104.6	87.2	86.5	83.3	96.7	102.9	129.8	119.3	129.5
H in char	% H	25.5	26.7	27.5	29.0	27.9	29.8	33.0	28.3	31.7	29.8	34.3	28.4
H in process water #	% H	47.6	43.1	44.7	42.7	46.5	41.5	39.8	43.7	48.0	46.6	37.1	36.1
Less H from hydrogen feed	% H	96.8	87.9	101.0	94.1	70.4	80.0	79.4	93.2	103.2	129.1	114.1	113.5
H identified (by definition)#	% H	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
O in organic liquids	% O	0.5	0.0	0.2	0.0	0.3	0.7	1.2	0.5	1.2	0.8	0.7	3.8
O in CO & CO2	% O	19.7	18.9	21.7	25.9	22.5	21.1	22.6	20.3	21.5	19.7	12.1	23.1
O in char	% O	8.8	8.9	9.4	7.3	9.3	9.9	10.6	10.1	9.8	10.1	18.2	10.0
O in process water #	% O	76.6	69.2	71.9	68.7	74.6	66.6	63.9	70.2	72.5	70.5	56.0	54.5
O identified #	% O	105.6	97.1	103.1	101.8	106.7	98.3	98.4	101.1	104.9	101.0	87.1	91.3
N in organic liquids	% N	2.4	6.4	3.1	0.7	9.4	9.3	6.0	4.5	5.6	0.7	3.4	1.3
N in char	% N	39.8	43.1	43.6	42.1	42.2	44.5	46.6	41.1	42.3	37.0	40.5	37.9
N identified	% N	42.2	49.5	46.6	42.8	51.6	53.7	52.6	45.6	47.9	37.7	44.0	39.2
S identified (all in the char)	% S	45.3	33.9	49.6	44.9	51.4	36.8	47.0	53.5	69.6	56.5	78.3	70.6
Ash indentified (in the char)	% ash	90.0	92.2	92.1	91.2	92.8	93.9	96.0	101.7	74.5	75.1	73.1	92.9

The unreacted hydrogen and the moisture from the coal feed are not included.

TABLE 5: BALANCES BY ELEMENTS

Expressed as "% Dry Coal"

Forestburg Coal

Test #		50	49	48	47	46	44	42	41	38	37	36	35
Reactor pressure	psi	2000	2000	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Reactor temperature	C	750	750	750	750	750	725	700	750	725	775	775	750
Hydrogen pre-heat temperature	C	740	750	750	755	750	775	700	750	725	730	710	720
Gas discharge temperature	C	660	665	660	655	650	630	620	660	635	680	655	630
Coal feed rate (dry)	g/h	1516	1676	1756	1548	1412	1276	1405	1595	952	1034	494	366
Hydrogen feed rate	g/h	1441	1532	1386	1206	1274	1276	1213	1069	1050	1037	938	596
Coal (dry) fed	g/test	1200	1200	1200	1200	1200	1196	1194	1196	1190	1181	335	903
C in organic liquids	% coal	14.12	14.30	13.04	12.03	14.06	13.25	11.08	11.73	11.90	12.16	13.08	10.46
C in gaseous HC's	% coal	14.99	13.61	14.03	14.85	12.40	12.41	11.83	13.60	13.25	16.25	14.92	16.56
C in CO & CO2	% coal	3.18	3.06	3.49	4.16	3.55	3.30	3.58	3.27	3.31	3.06	1.89	3.60
C in char	% coal	31.24	30.98	33.05	33.28	31.83	32.70	34.84	32.38	32.14	30.88	32.79	29.09
CARBON IDENTIFIED	% coal	63.54	61.96	63.61	64.31	61.83	61.65	61.33	60.99	60.60	62.36	62.68	59.71
C in coal	% coal	63.55	63.55	63.55	63.55	63.55	63.55	63.55	63.55	61.38	61.38	61.38	61.38
H in organic liquids	% coal	0.82	0.92	1.32	0.77	0.39	0.97	1.02	1.07	0.81	0.90	0.93	0.77
H in gaseous HC's	% coal	4.59	4.23	4.31	4.57	3.81	3.78	3.64	4.23	4.07	5.13	4.72	5.12
H in char	% coal	1.11	1.17	1.20	1.27	1.22	1.30	1.44	1.24	1.25	1.18	1.36	1.12
H in process water	% coal	2.08	1.88	1.96	1.87	2.03	1.81	1.74	1.91	1.90	1.84	1.47	1.43
Less H from hydrogen feed	% coal	4.23	3.84	4.41	4.11	3.08	3.50	3.47	4.07	4.08	5.10	4.51	4.49
HYDROGEN IDENTIFIED	% coal	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	3.95	3.95	3.95	3.95
H in coal	% coal	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	3.95	3.95	3.95	3.95
O in organic liquids	% coal	0.10	0.00	0.04	0.00	0.06	0.16	0.26	0.11	0.24	0.16	0.15	0.78
O in CO & CO2	% coal	4.25	4.08	4.68	5.59	4.85	4.55	4.88	4.37	4.46	4.08	2.52	4.80
O in char	% coal	1.91	1.93	2.02	1.58	2.01	2.14	2.29	2.19	2.03	2.10	3.79	2.07
O in process water	% coal	16.53	14.95	15.52	14.82	16.11	14.38	13.80	15.15	15.06	14.64	11.63	11.32
OXYGEN IDENTIFIED	% coal	22.79	20.96	22.26	21.98	23.04	21.23	21.24	21.83	21.79	20.98	18.09	18.97
O in coal	% coal	21.59	21.59	21.59	21.59	21.59	21.59	21.59	21.59	20.78	20.78	20.78	20.78
N in organic liquids	% coal	0.03	0.08	0.04	0.01	0.12	0.12	0.08	0.06	0.07	0.01	0.04	0.02
N in char	% coal	0.50	0.54	0.55	0 53	0.53	0.56	0.58	0.52	0.53	0.46	0.51	0.47
NITROGEN IDENTIFIED	% coal	0.53	0.62	0.58	0.54	0.65	0.67	0.66	0.57	0.60	0.47	0.55	0.49
N in coal	% coal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
SULPHUR IN THE CHAR	% coal	0.17	0.14	0.19	0.17	0.20	0.14	0.18	0.20	0.24	0.19	0.27	0.24
S in coal	% coal	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.34	0.34	0.34	0.34
ASH IN THE CHAR	% coal	7.97	8.17	8.15	8.07	8.22	8.49	8.51	9.01	9.16	9.24	8.99	11.43
Ash in coal	% coal	8.86	8.86	8.86	8.86	8.86	8.86	8.86	8.86	12.30	12.30	12.30	12.30
PRODUCTS IDENTIFIED	% coal	99.37	96.21	99.17	99.45	98.31	96.55	96.28	96.97	96.35	97.20	94.53	94.80
UNACCOUNTED	% coal	0.63	3.79	0.83	0.55	1.69	3.45	3.72	3.03	3.65	2.80	5.47	5.20

TABLE 6: OVERVIEW OF MASS BALANCES FOR ALL VALID "FORESTBURG" TESTS AT O.R.F.

page 1 of 3: Campaign 2, Class 1 tests

Test #		50	49	48	47	46	44	42	41	38	37	36	35
Reactor pressure	psi	2000	2000	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Reactor temperature	C	750	750	750	750	750	725	700	750	725	775	775	750
Coal feed rate (dry)	g/h	1516	1636	1756	1548	1412	1276	1405	1595	952	1034	494	366
Hydrogen feed rate	g/h	1441	1532	1386	1206	1274	1292	1213	1069	1050	1037	938	596
Hydrogen added to products	% coal	4.2	3.8	4.4	4.1	3.1	3.5	3.5	4.1	4.1	5.1	4.5	4.5
Coal (dry)	% coal	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FEED #	% coal	104.2	103.8	104.4	104.1	103.1	103.5	103.5	104.1	104.1	105.1	104.5	104.5
Liquids from condensers	% coal	33.7	32.1	31.9	29.5	32.8	31.0	28.3	30.4	30.3	30.5	30.0	29.3
less moisture from coal	% coal	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.7	2.7	4.6
Liquid products #	% coal	33.7	32.1	31.9	29.5	32.8	30.7	28.0	30.0	30.0	29.7	27.3	24.8
Gaseous hydrocarbons	% coal	19.6	17.8	18.3	19.4	16.2	16.2	15.5	17.8	17.3	21.4	19.6	21.7
CO & CO2	% coal	7.4	7.1	8.2	9.8	8.4	7.8	8.5	7.6	7.8	7.1	4.4	8.4
Gaseous products #	% coal	27.0	25.0	26.5	29.2	24.6	24.0	23.9	25.5	25.1	28.5	24.1	30.1
Char	% coal	42.9	42.9	45.2	44.9	44.0	45.3	47.8	45.5	45.4	44.1	47.7	44.4
UNACCOUNTED	% coal	0.6	3.8	0.8	0.6	1.7	3.4	3.7	3.0	3.7	2.8	5.5	5.2
Unacc'd + liquid products	% coal	34.3	35.9	32.7	30.0	34.5	34.1	31.7	33.1	33.6	32.5	32.8	30.0
Duration of purge	min	15	21	21	15	15	24	26	35	24	31	0	15
Coal (dry) fed	g/test	1200	1200	1200	1200	1200	1196	1194	1196	1190	1181	355	903
Unaccounted	g/test	7.6	45.5	9.9	6.6	20.3	41.2	44.4	36.2	43.5	33.0	19.4	47.0

The unreacted hydrogen and the moisture from the coal feed are not included.

TABLE 6: OVERVIEW OF MASS BALANCES FOR ALL VALID "FORESTBURG" TESTS AT O.R.F.

page 2 of 3:

		Campaign 2, Class 2 Tests					Campaign 1 Final Tests					
Test #		34	29	28	27	26	23	20	19	18	17	16c
Reactor pressure	psi	1800	1800	1800	1800	1800	1750	1750	1750	1750	1750	1500
Reactor temperature	C	750	755	755	755	755	800	800	725	725	790	800
Coal feed rate (dry)	g/h	169	122	61	96	205	591	434	439	482	483	487
Hydrogen feed rate	g/h	640	664	606	662	936	426	780	1173	558	1091	744
Hydrogen added to products	% coal	0.5	4.2	3.8	4.8	3.9	5.2	4.4	3.0	3.3	4.3	3.5
Coal (dry)	% coal	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FEED #	% coal	100.5	104.2	103.8	104.8	103.9	105.2	104.4	103.0	103.3	104.3	103.5
Liquids from condensers	% coal	9.2	27.5	25.7	24.0	19.7	21.5	30.0	26.2	24.4	26.1	21.9
less moisture from coal	% coal	3.7	5.0	10.1	9.3	11.0	2.4	2.4	2.4	2.4	2.4	2.4
Liquid products #	% coal	5.5	22.5	15.6	14.7	8.7	19.2	27.6	23.8	22.0	23.7	19.5
Gaseous hydrocarbons	% coal	2.3	17.8	16.0	19.7	16.8	21.4	18.4	12.9	14.7	18.2	14.8
CO & CO2	% coal	4.4	3.0	3.4	9.3	7.6	7.9	7.0	7.9	7.9	6.8	8.2
Gaseous products #	% coal	6.7	20.8	19.3	29.0	24.4	29.3	25.4	20.8	22.5	25.0	23.0
Char	% coal	68.1	40.6	47.7	48.0	50.5	51.4	49.1	50.6	52.8	47.7	51.9
UNACCOUNTED	% coal	20.3	20.4	21.2	13.0	20.3	5.4	2.3	7.8	5.9	8.0	9.2
Unacc'd + liquid products	% coal	25.8	42.8	36.8	27.7	29.0	24.6	29.9	31.6	27.9	31.7	28.7
Duration of purge	min	14	24	10	33	10	10	10	10	5	11	15
Coal (dry) fed	g/test	384	210	145	164	228	751	556	440	898	611	580
Unaccounted	g/test	78.0	42.7	30.7	21.4	46.2	40.5	12.6	34.2	53.4	48.9	53.0

The unreacted hydrogen and the moisture from the coal feed are not included.

TABLE 6: OVERVIEW OF MASS BALANCES FOR ALL VALID "FORESTBURG" TESTS AT O.R.F.

page 3 of 3:

		Campaign 1 Early Tests				Commissioning Tests				
Test #		15	14	13	12	11	10	9	8	6
Reactor pressure	psi	1250	1000	1000	1000	1000	1500	1500	1000	1000
Reactor temperature	C	800	800	750	650	750	800	700	700	490
Coal feed rate (dry)	g/h	469	477	487	476	704	826	856	896	943
Hydrogen feed rate	g/h	602	1047	1041	1442	1056	1057	974	950	1878
Hydrogen added to products	% coal	3.3	2.9	2.2	0.0	2.2	4.4	3.1	2.2	0.0
Coal (dry)	% coal	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
FEED #	% coal	103.3	102.9	102.2	100.0	102.2	104.4	103.1	102.2	100.0
Liquids from condensers	% coal	23.6	23.4	21.7	17.1	25.9	27.4	25.4	16.1	10.7
less moisture from coal	% coal	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Liquid products #	% coal	21.2	21.0	19.3	14.7	23.6	25.0	23.0	13.7	8.3
Gaseous hydrocarbons	% coal	13.9	12.0	9.3	0.0	9.5	18.4	13.4	9.6	0.0
CO & CO2	% coal	9.1	8.9	7.6	7.7	6.1	6.5	7.5	7.5	0.0
Gaseous products #	% coal	23.0	20.9	16.8	7.7	15.5	24.9	20.9	17.1	0.0
Char	% coal	51.4	54.3	56.3	66.3	52.3	45.1	51.9	39.0	86.8
UNACCOUNTED	% coal	7.8	6.7	9.7	11.3	10.8	9.4	7.3	12.4	4.9
Unacc'd + liquid products	% coal	29.0	27.7	29.1	26.1	34.4	34.4	30.3	26.1	13.2
Duration of purge	min	0	10	0	0	0	0	0	0	0
Coal (dry) fed	g/test	792	582	586	569	720	629	862	461	535
Unaccounted	g/test	61.8	38.8	57.1	64.4	77.9	59.2	62.9	57.3	26.1

The unreacted hydrogen and the moisture from the coal feed are not included.

TABLE 7: ANALYSES OF COAL, CHAR AND GASEOUS PRODUCTS

Forestburg Coal

Test #		50	49	48	47	46	44	42	41	38	37	36	35
COAL ANALYSIS:													
C in coal	% coal	63.55	63.55	63.55	63.55	63.55	63.55	63.55	63.55	61.38	61.38	61.38	61.38
H in coal	% coal	4.37	4.37	4.37	4.37	4.37	4.37	4.37	4.37	3.95	3.95	3.95	3.95
O in coal	% coal	21.59	21.59	21.59	21.59	21.59	21.59	21.59	21.59	20.78	20.78	20.78	20.78
N in coal	% coal	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
S in coal	% coal	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.34	0.34	0.34	0.34
Ash in coal	% coal	8.86	8.86	8.86	8.86	8.86	8.86	8.86	8.86	12.30	12.30	12.30	12.30
Total	% coal	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
CHAR ANALYSIS													
C in char	% char	72.81	72.18	73.18	74.13	72.33	72.14	72.83	71.11	70.87	70.09	68.74	65.49
H in char	% char	2.60	2.72	2.66	2.82	2.77	2.88	3.01	2.71	2.76	2.68	2.85	2.52
O in char	% char	4.45	4.49	4.47	3.51	4.57	4.72	4.78	4.81	4.48	4.78	7.94	4.65
N in char	% char	1.16	1.26	1.21	1.18	1.20	1.23	1.22	1.13	1.16	1.05	1.06	1.07
S in char	% char	0.40	0.32	0.42	0.38	0.45	0.31	0.38	0.45	0.53	0.44	0.57	0.55
Ash in char	% char	18.57	19.03	18.05	17.98	18.68	18.73	17.78	19.79	20.20	20.97	18.84	25.72
Total	% char	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
GAS ANALYSIS (average of all G.C. readings)													
Duration of test	min	48	44	41	47	51	56	51	45	75	69	43	148
# of Samples		4	4	4	4	5	6	5	5	6	7	4	12
CO aver	% mol	0.57	0.56	0.76	0.91	0.65	0.53	0.69	0.84	0.51	0.52	0.17	0.37
CO2 aver	% mol	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.00	0.01	0.00	0.00	0.00
CH4 aver	% mol	1.74	1.75	2.02	2.18	1.54	1.32	1.56	2.45	1.35	2.12	1.02	1.18
C2H6 aver	% mol	0.47	0.37	0.52	0.54	0.39	0.38	0.39	0.52	0.35	0.33	0.16	0.27
H2 aver	% mol	97.21	97.33	96.70	96.37	97.40	97.75	97.35	96.19	97.79	97.02	98.65	98.17
Total	% mol	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 8: ANALYSES OF LIQUID PRODUCTS

Forestburg Coal

Test #		50	49	48	47	46	44	42	41	38	37	36	35
FIRST CONDENSER:													
Organic Liquids	% coal	12.24	12.43	11.59	9.71	12.12	12.41	10.82	10.71	10.09	10.22	9.68	7.98
Water	% coal	18.61	16.83	17.47	16.69	18.14	16.53	15.85	17.39	17.28	17.23	15.81	17.32
All liquids	% coal	30.84	29.26	29.06	26.40	30.26	28.94	26.67	28.09	27.37	27.46	25.49	25.30
C in organic liquids	% of O.L.	94.06	93.43	90.44	95.48	96.89	91.47	89.28	90.23	91.55	92.05	92.72	86.52
H in organic liquids	% of O.L.	5.07	5.91	8.92	4.49	1.67	6.51	7.89	8.43	5.79	6.71	6.68	6.24
N in organic liquids	% of O.L.	0.21	0.64	0.32	0.02	0.93	0.90	0.67	0.47	0.69	0.06	0.33	0.08
O in organic liquids	% of O.L.	0.65	0.00	0.30	0.00	0.49	1.11	2.16	0.86	1.95	1.17	0.86	7.15
SECOND CONDENSER:													
Organic Liquids	% coal	2.82	2.94	2.90	3.12	2.52	2.06	1.59	2.27	2.93	3.02	4.54	3.92
C in organic liquids	% of O.L.	92.90	91.50	88.41	88.23	91.99	91.86	88.75	91.44	91.28	91.15	90.45	90.64
H in organic liquids	% of O.L.	6.91	6.45	9.77	10.85	7.33	7.84	10.30	7.53	7.87	7.14	7.46	7.04
N in organic liquids	% of O.L.	0.16	0.03	0.03	0.22	0.24	0.20	0.19	0.24	0.02	0.12	0.23	0.26
O in organic liquids	% of O.L.	0.89	0.00	0.31	0.00	0.17	0.99	1.83	0.86	1.58	1.25	1.49	5.43
C atom / H atom	ratio	1.13	1.19	0.76	0.68	1.05	0.98	0.72	1.02	0.97	1.07	1.02	1.08
Gas Chromatograph Data:													
Toluene	% of O.L.	0.94	1.35	0.83	0.97	1.81	4.36	9.14	1.03	3.08	0.48	0.60	0.99
Benzene	% of O.L.	63.13	74.57	52.35	62.94	85.37	72.01	70.87	83.23	79.95	81.06	66.33	87.76
O-Xylene	% of O.L.	0.05	0.25	0.02	0.02	0.05	0.08	0.17	0.02	0.05	0.01	0.04	0.05
p-Xylene	% of O.L.						0.04	0.17					0.01
m-Xylene	% of O.L.	0.01	0.01				0.06	0.22		0.01		0.01	0.01
Naphtalene	% of O.L.	0.28	0.65	0.44	0.82	1.29	0.33	0.51	1.02	0.55	0.40	1.25	0.84
Total Identified	% of O.L.	64.41	76.83	53.64	64.75	88.52	76.88	81.08	85.30	83.64	81.95	68.23	89.66
Of this C	% of O.L.	59.42	70.87	49.48	59.74	81.67	70.89	74.71	78.70	77.14	75.61	62.96	82.72
Of this H	% of O.L.	4.99	5.96	4.16	5.01	6.85	5.99	6.37	6.60	6.50	6.34	5.27	6.94
C atom / H atom	ratio	1.00	1.00	1.00	1.00	1.00	0.99	0.98	1.00	1.00	1.00	1.00	1.00
BOTH CONDENSERS:													
C in organic liquids	% coal	14.12	14.30	13.04	12.03	14.06	13.25	11.08	11.73	11.90	12.16	13.08	10.46
H in organic liquids	% coal	0.82	0.92	1.32	0.77	0.39	0.97	1.02	1.07	0.81	0.90	0.93	0.77
N in organic liquids	% coal	0.03	0.08	0.04	0.01	0.12	0.12	0.08	0.06	0.07	0.01	0.04	0.02
O in organic liquids	% coal	0.10	0.00	0.04	0.00	0.06	0.16	0.26	0.11	0.24	0.16	0.15	0.78
Organic Liquids	% coal	15.07	15.31	14.44	12.81	14.63	14.49	12.43	12.98	13.03	13.23	14.20	12.03
Process water	% coal	18.61	16.83	17.47	16.69	18.14	16.19	15.54	17.06	16.95	16.49	13.10	12.75
Moisture from the coal	% coal	0.00	0.00	0.00	0.00	0.00	0.33	0.31	0.33	0.33	0.75	2.71	4.57

TABLE 9: GAS CHROMATOGRAPH READINGS

Forestburg Coal

Test #			50	49	48	47	46	44	42	41	38	37	36	35
# of Samples			4	4	4	4	5	6	5	5	6	7	4	12
CO reading	# 1	% mol	0.599	0.336	0.806	0.960	0.661	0.548	0.756	0.852	0.626	0.497	0.166	0.535
	# 2	% mol	0.534	0.548	0.806	0.933	0.595	0.517	0.719	0.863	0.449	0.624	0.162	0.415
	# 3	% mol	0.573	0.564	0.710	0.874	0.663	0.483	0.662	0.914	0.504	0.557	0.180	0.381
	# 4	% mol	0.538	0.577	0.700	0.857	0.686	0.539	0.658	0.831	0.477	0.531	0.167	0.382
	# 5	% mol					0.632	0.570	0.648	0.730	0.495	0.520		0.372
	# 6	% mol						0.549			0.488	0.515		0.382
	# 7	% mol										0.428		0.367
	# 8	% mol												0.385
	# 9	% mol												0.331
	#10	% mol												0.323
	#11	% mol												0.314
	#12	% mol												0.311
CO2 read.	# 1	% mol			0.012	0.023	0.078	0.032	0.016		0.022			
	# 2	% mol	0.001	0.001	0.003	0.002	0.002	0.008	0.006		0.004			
	# 3	% mol	0.001	0.001	0.002	0.002	0.003	0.017	0.016	0.002	0.002			
	# 4	% mol	0.001	0.001	0.003	0.002	0.003	0.019	0.024	0.003	0.002		0.001	
	# 5	% mol					0.004	0.020	0.024	0.002	0.001			
	# 6	% mol						0.020		0.002	0.001			
	# 7	% mol												
	# 8	% mol												
	# 9	% mol												
	#10	% mol												
	#11	% mol												
	#12	% mol												
CH4 read.	# 1	% mol	1.650	1.760	2.231	2.436	1.620	1.331	1.773	2.358	1.690	1.813	1.212	1.751
	# 2	% mol	1.741	1.717	2.076	2.232	1.428	1.222	1.775	2.458	1.091	2.474	0.779	1.376
	# 3	% mol	1.817	1.729	1.887	2.048	1.554	1.189	1.389	2.381	1.346	2.230	1.344	0.904
	# 4	% mol	1.770	1.777	1.866	2.005	1.598	1.334	1.397	2.398	1.274	2.176	0.749	1.064
	# 5	% mol					1.481	1.430	1.452	2.233	1.346	2.032		1.264
	# 6	% mol						1.385			1.369	2.062		1.097
	# 7	% mol										2.070		1.242
	# 8	% mol												1.238
	# 9	% mol												1.122
	#10	% mol												1.092
	#11	% mol												0.906
	#12	% mol												1.125
C2H6 read.	# 1	% mol	0.256	0.369	0.625	0.527	0.554	0.398	0.374	0.410	0.491	0.195	0.233	0.189
	# 2	% mol	0.495	0.370	0.531	0.542	0.295	0.321	0.350	0.457	0.278	0.403	0.093	0.448
	# 3	% mol	0.560	0.396	0.444	0.542	0.338	0.354	0.346	0.595	0.288	0.416	0.186	0.138
	# 4	% mol	0.583	0.327	0.486	0.542	0.373	0.388	0.412	0.618	0.284	0.319	0.113	0.092
	# 5	% mol					0.414	0.439	0.460	0.527	0.338	0.321		0.396
	# 6	% mol						0.403			0.385	0.321		0.265
	# 7	% mol										0.333		0.175
	# 8	% mol												0.435
	# 9	% mol												0.299
	#10	% mol												0.377
	#11	% mol												0.256
	#12	% mol												0.174

TABLE 10: TEST DATA WITH PRINCE MINE COAL

		Campaign 2 1985		Campaign 1 1984		
Test #		45	43	24	22	21
Date	month.day	3.14	3.08	3.30	3.26	3.22
Duration of test	min	34	60	69	61	49
Reactor pressure	psi	1800	1800	1750	1750	1750
Reactor pressure	MPa	12.4	12.4	12.1	12.1	12.1
Coal (dry) fed during test	g	BH/A	BH/A	BH/A	BH/A	BH/A
Coal feed rate (dry)	g/h	BH/A	BH/A	BH/A	BH/A	BH/A
Hydrogen feed rate	g/h	1297	1260	922	943	1143
Pre-heater voltage setting	%	66	off	69	62	70
Hydr. preheat, start of feed	C	759	off	745	740	BH/A
Hydr. preheat, end of feed	C	759	off	751	751	BH/A
Reactor temperature	C	775	750	750	750	750
B1 furn. at start of feed	C		511	360		
B1 furn. at end of feed	C		500	501		
B2 furn. at start of feed	C		668			
B2 furn. at end of feed	C		628			
Reactor wall B1/B2 before feed	C	536	518	Not installed		
Reactor wall B1/B2, early	C	560	520			
Reactor wall B1/B2 end of feed	C	557	514			
Reactor wall B1/B2 after feed	C	557	499			
Aver. increase during feed	C	2	9			
Reactor wall B3/B4 before feed	C	591	347	Not installed		
Reactor wall B3/B4, early	C	596	331			
Reactor wall B3/B4 end of feed	C	618	311			
Reactor wall B3/B4 after feed	C	622	327			
Aver. increase during feed	C	1	-16			
Gas discharge, before feed	C	615	603	520	525	520
Gas discharge, early	C	628	612	520	528	525
Gas discharge, end of feed	C	628	610	515	528	525
Gas discharge, after feed	C	610	602	515	BH/A	BH/A
Aver. increase during feed	C	16	9	0	BH/A	BH/A

TABLE 11: GASEOUS PRODUCTS WITH PRINCE MINE COAL

Test #			43	45
Times of readings from start of the coal feeder:				
	# 1	min	3.0	15.0
	# 2	min	7.5	19.0
	# 3	min	10.5	23.0
	# 4	min	13.5	27.0
	# 5	min	16.5	31.0
	# 6	min		35.0
# of Samples			5	6
CO reading	# 1	% mol	0.051	1.069
	# 2	% mol	0.034	1.136
	# 3	% mol	0.017	0.440
	# 4	% mol	0.011	0.214
	# 5	% mol	0.009	0.065
	# 6	% mol		0.024
CO2 read.	# 1	% mol	0.158	0.243
	# 2	% mol	0.060	0.138
	# 3	% mol	0.026	#N/A
	# 4	% mol	0.014	0.022
	# 5	% mol	0.010	0.007
	# 6	% mol		0.004
CH4 read.	# 1	% mol	0.429	0.540
	# 2	% mol	0.228	0.491
	# 3	% mol	0.097	#N/A
	# 4	% mol	0.060	0.360
	# 5	% mol	0.064	0.184
	# 6	% mol		0.105
C2H6 read.	# 1	% mol	0.305	0.243
	# 2	% mol	0.096	0.113
	# 3	% mol	0.048	#N/A
	# 4	% mol	0.024	0.068
	# 5	% mol	0.023	0.037
	# 6	% mol		0.013
Gases during the #1 readings:				
Gaseous HC's		g/h	103.1	92.9
CO		g/h	9.2	174.3
CO2		g/h	44.6	62.2
C in CO & CO2		g/h	16.1	91.7
C in gaseous HC's		g/h	80.1	71.7
O in CO & CO2		g/h	37.7	144.8
H in gaseous HC's		g/h	22.9	21.2
Process gases		g/h	156.9	329.5

Table 12

Coal Sizing

Forestburg Coal - All Valid Tests Excepting #36

Microns	Mesh	% by Weight
149 - 210	-65 + 100	25
105 - 149	-100 + 150	75

Forestburg Coal - Test #36 - Left Over Coal from the Hopper

>210	+ 55	0.1
149 - 210	-65 + 100	3.3
105 - 149	-100 + 150	32.1
<105	-150	64.4

Prince Mine Coal - Campaign 1

>297	+ 50	3
210 - 297	- 50 + 70	25
177 - 210	- 70 + 80	32
149 - 177	- 80 + 100	16
105 - 149	-100 + 140	19
105>	-140	5

Prince Mine Coal and Dolomite - Campaign 2

149 - 210	- 65 + 100	75
105 - 149	-100 + 150	25

TABLE 13: PREHEATER PERFORMANCE

Page 1 of 2

Test	Hydrogen		Net heat		Preheater		Note	TPe	TPi	TJe	TJi
	flow	temp.	into H	setting	power	effic.					
#	L/hr	C	kW	%	kVA	%	#	C	C	C	C
10	11740	750	3.2	ON/A	ON/A	ON/A	1	726		760	
11	11730	840	3.6	ON/A	ON/A	ON/A	1	774	867	770	867
12	16819	650	3.8	ON/A	ON/A	ON/A	1	500		612	
13	11562	750	3.2	50	6.6	48		712		756	
14	11628	806	3.4	61	9.8	35		763		839	
15	6694	901	2.0	64	10.8	18	2	832	824	889	964
16	8269	800	2.4	66	11.5	21	3	435		464	
17	12125	800	3.5	66	11.5	31		489		559	
18	6195	719	1.6	60	9.5	17		570	516	640	567
19	13020	723	3.4	52	7.1	48		582		538	544
20	8664	800	2.5	68	12.2	21		713		625	
23	4738	592	1.0	70	12.9	8	4	374	318		
25	9115	730	2.4	85	19.0	13	5	663	684	650	
26	10402	763	2.9	49	6.3	46	6	620			
27	7357	793	2.1	60	9.5	22		684	712	740	770
28	6737	741	1.8	66	11.5	16		607	634	576	604
29	7383	759	2.0	67	11.8	17		757	782		
30	2500	650	0.6	60	9.5	6	7	544	676		
31	7600	700	1.9	60	9.5	20		623	643	537	560
33	7400	720	1.9	68	12.2	16		661	683	545	578
34	7107	750	1.9	68	12.2	16		729	766	573	599
35	6623	735	1.8	68	12.2	15	8	743	778	560	605
36	10422	713	2.7	70	12.9	21		670		530	
37	11520	740	3.1	70	12.9	24		701	737	606	721
38	11672	725	3.1	54	7.7	40		650		540	
39	11600	750	3.2	60	9.5	34		580		510	
41	13771	750	3.8	59	9.2	41		649		534	
42	14046	700	3.6	53	7.4	49		550		485	
44	14430	775	4.1	65	11.1	37		710		610	
45	16126	772	4.5	66	9.5	48	9	663		482	
46	15000	750	4.1	68	10.1	41		620		590	
47	14000	762	3.9	75	12.3	32		677		622	
48	15400	750	4.2	72	11.3	37		685		560	
49	17027	756	4.7	75	12.3	38		680		570	
50	14016	740	4.3	75	12.3	35		631		601	

TABLE 13: PREHEATER PERFORMANCE

Notes to "Preheater Performance" Table.

General

(a) Flowrates, temperatures and settings changed slightly during the tests. The tabulated data refer to periods in equilibrium.

(b) The readings from the spring loaded thermocouple on the discharge side of the pipe, taken early and late during the tests, are given as TPe and TP1.
TJe and TJ1 are the equivalent data from the high temperatuwe junction.

Details

#1 The preheater power setting was not recorded. It was probably no more than 50%.

#2 After the completed test the preheater pipe was found to be bulged.

#3 The damaged section was cut out. Spring loaded thermocouples were installed in the F1 and F2 positions.

#4 The preheater was welded to the reactor. The section between the junction and the reactor was insulated. At this test the H2 temp. thermocouple slipped and gave low indications.

#5 The preheater pipe burst after 50 min.

#6 About one-half of the pipe was replaced with a clean surfaced piece. The shroud around the pipe was extended to the full length. The mild steel high temp. junction was replaced with a smaller SS piece.

#7 The H2 flowrate dropped drasticly and the pipe burst. The damaged section was cut out.

#8 From this test on a small portion of the H2 flow was set to by-pass the preheater in order to cool the feeder motor.

#9 New pipe, length inncreased from 122 to 147". In the calculation of the heating power allowance was made for the increased pipe resistance.

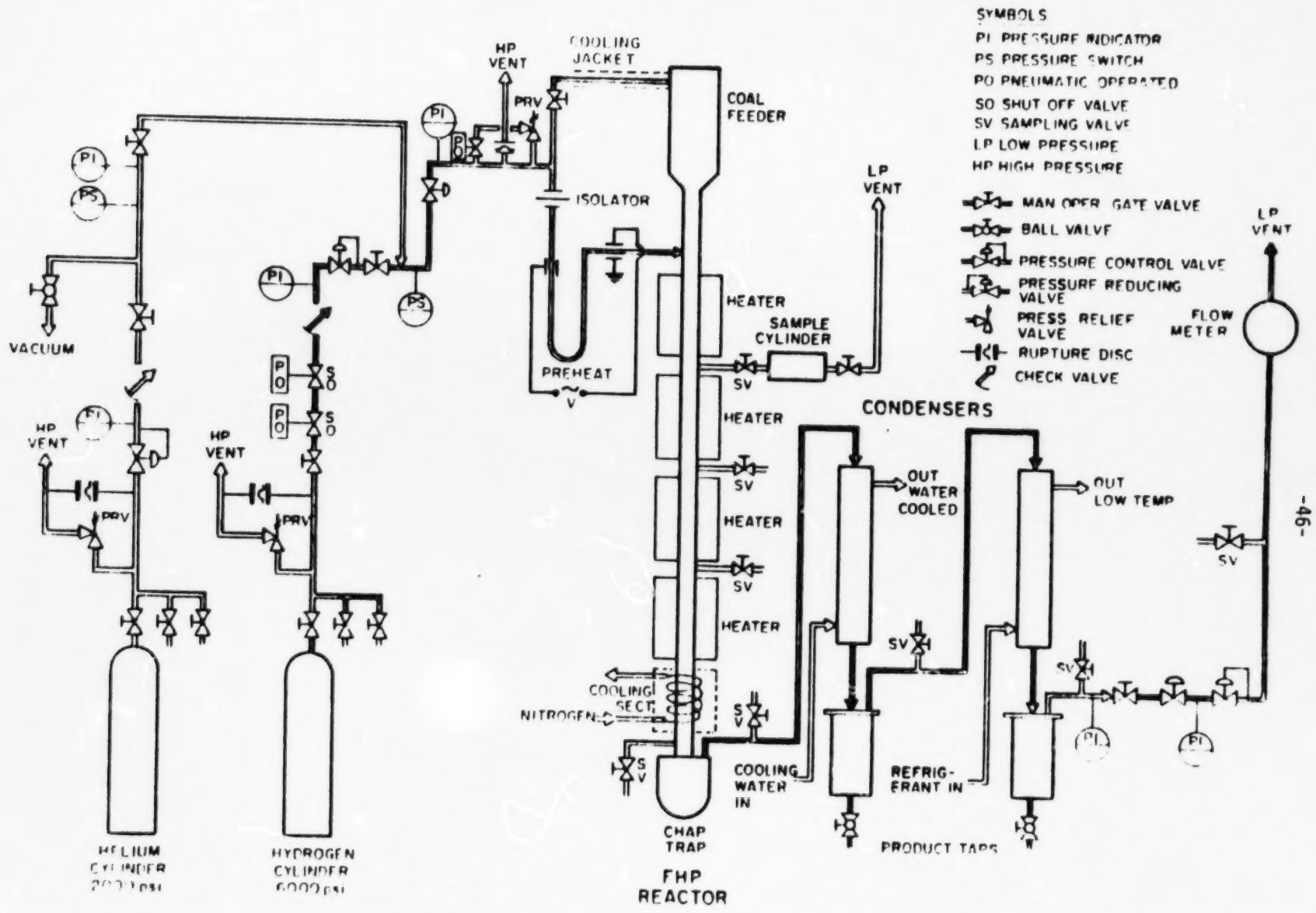


FIGURE 1

CANMET and ONTARIO RESEARCH FOUNDATION

PROCESS FLOW DIAGRAM – FLASH HYDROPYROLYSIS PILOT UNIT

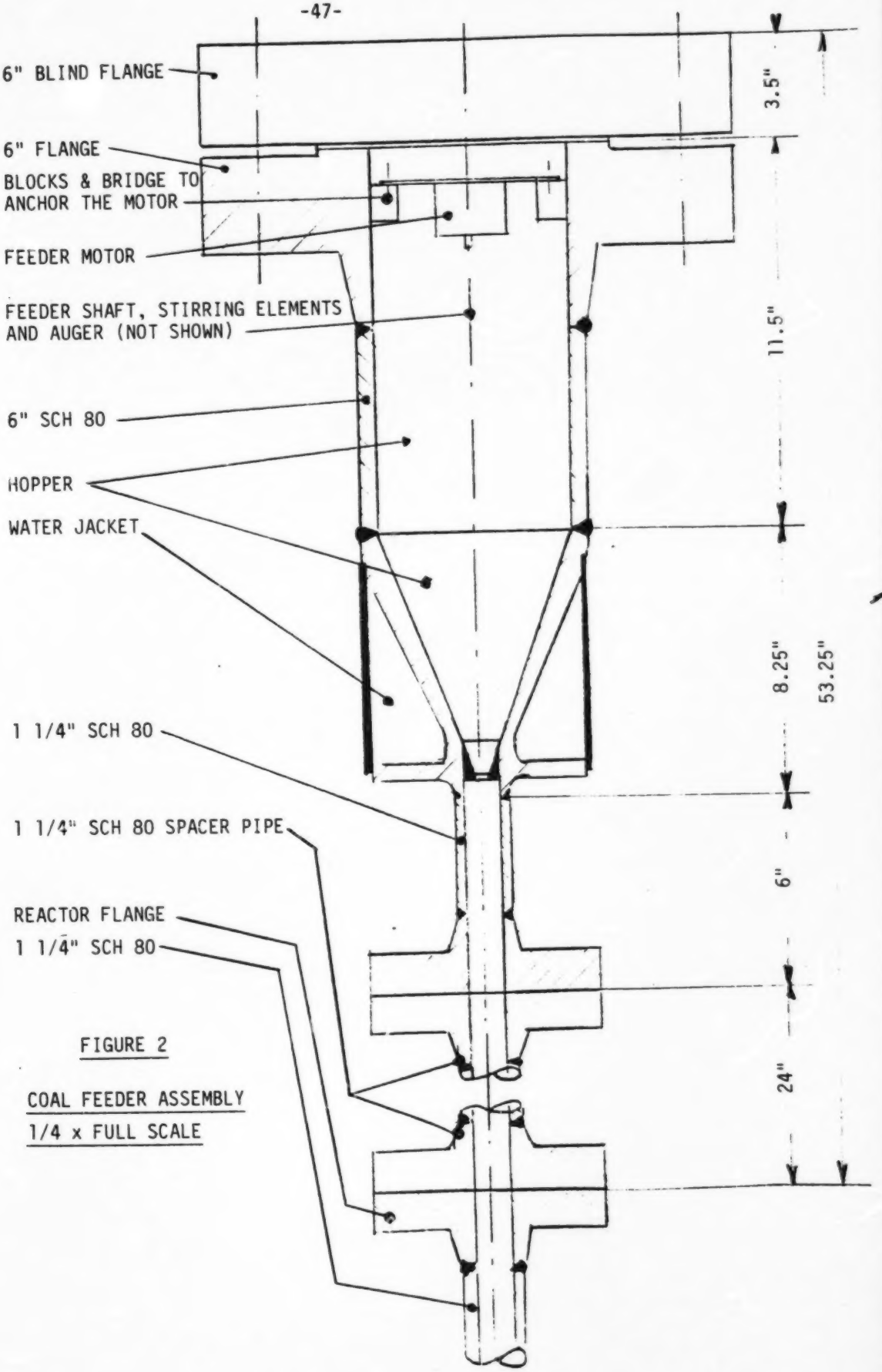
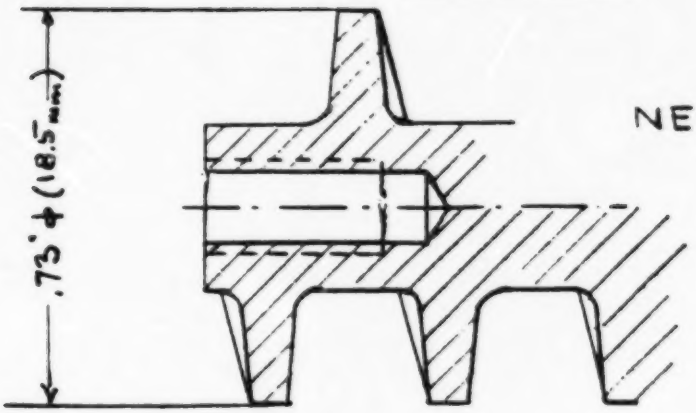


FIGURE 2

COAL FEEDER ASSEMBLY

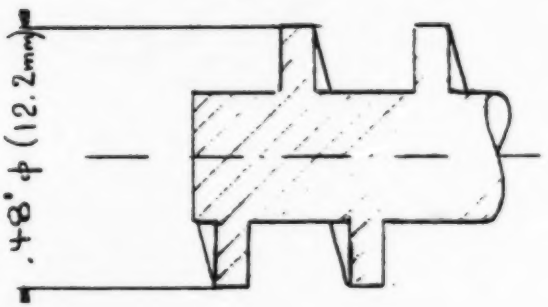
1/4 x FULL SCALE

FIGURE 3: Augers



NEW AUGER

.73 ϕ x 3 T.P.I.



ORIGINAL AUGER

.48 ϕ x 4 T.P.I.

3 x FULL SCALE

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APPENDIX 1

THE EFFECT OF THE TEMPERATURES ON HYDROCARBON PRODUCTION

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Appendix 1
THE EFFECT OF THE TEMPERATURES ON HYDROCARBON PRODUCTION

1. Conclusions

1.1 Within the tested temperature range the combined masses of the organic liquids ("OL") - primarily liquid hydrocarbons - and gaseous hydrocarbons ("GHC") increased with the temperatures.

2. The production on organic liquids depended also on the rapidity of the quenching. This is indicated by the test data, but the factors affecting this are not apparent.

2. General

The relationships are well discernible, but not entirely consistent for the following reasons:

(a) The temperatures affecting the process do change in the length of the reactor, hence these can not be expressed with a single number. This is discussed in detail in the following.

(b) The carbon balances lie in a narrow range. In eleven out of twelve runs under consideration the carbon content in OL's and GHC's range from 46.3 to 39.9%.

These balances depend on the test data. In the early runs the "unaccounted" item in the mass balances was as high as 5.5% of the dry coal, but it was reduced to less than 1% in the final runs. While this item represents primarily process water, it includes some OL's.

Chemical analyses of the coal, char, liquid and gaseous products are probably less accurate than the test data.

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3. Temperature Effects

The details of the data are given in Table 2. The attached tables A1 and A2, which differ only in the order of the columns, show only the average values for clarity.

3.1 Preheater

There is a short length of insulated pipe between the "hydrogen preheat temperature" thermocouple and the reactor, thus there was a small drop here.

In seven of the twelve tests the planned temperatures could not be obtained, thus the control was set to "constant power" (as opposed to "constant temperature"), hence the temperatures increased during the runs.

3.2 Reactor Wall

The controls maintained the reactor wall temperatures at the set values within 1°C with on/off switching. The exception was the #1 (top) furnace, which in five runs did not have the power to do this.

The data seems to indicate that the gas/wall heat exchange was not sufficient to assure the equalization of the temperatures.

3.3 Gas Temperatures

The gas discharge temperatures were measured below the #4 furnace. While these were certainly lower than those in the heated section, the difference might not have been very large. The likelihood is that the 750°C reactor settings represented only 700°C gas temperatures. The differences between the "hydrogen only" and "feed" conditions were quite pronounced.

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Downstream of this thermocouple the gases cooled in the uninsulated reactor. The quenching process became rapid in the large mass of the bare char trap, where the gas temperatures were about 200°C at the beginning and 320°C at the end of the runs.

3.4 Coal - Hydrogen Heat Exchange

The coal was at 20-40°C temperature and contained 0-3% moisture when it was mixed with the hot hydrogen. On account of the intimate contact between the gas and the coal particles, it can be assumed that most of the heat was taken from the hydrogen.

Two extreme examples, calculated on the basis of coal-hydrogen heat exchange, indicate the magnitude of this effect.

Run #	36	48
Hydrogen preheat, °C	710	748
Hydrogen/coal ratio	1.9	0.79
Moisture content of the coal, %	2.7	0
Common temperature, °C	679	676
#1 Furnace, average °C	775	738
Hydrogen rate, g/hr.	938	1386

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In practice, in run #36 the gas moved relatively slowly by the hot reactor walls, hence the common temperature was probably significantly higher than the calculated value. In run #48 the difference was probably very much less.

It takes approximately 860 kJ to heat 1 kg coal to 700°C. With a typical 1200 g/hr. rate 290 w power was absorbed.

3.5 Exothermic Reactions

Typically, the coal contained 21% oxygen. Of this, 70% was converted to H_2O and 20% to CO. The heats of formation were 2220 and 290 J/g coal, respectively. With the typical 1200 g/hr. rates 840 w power was generated from this source.

4. DISCUSSION OF THE TABLES

In Table A1 and Figure A1 the runs are arranged in the order of the carbon in the organic liquids and gaseous hydrocarbons. Some of the relevant data are "highlighted":

(a) High pressures promote the conversion.
(b) With unusually high hydrogen/coal ratios the cooling effect of the coal is less pronounced than with unusually low ratios.
(c) For run #36 an unusually fine grind of coal was used.

With these additional considerations it appears that high temperatures promote the conversion.

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In Table A2 and Figure A2 the same data is arranged in order of organic liquids. This order is similar to that in Table A1, but there are some changes.

High conversion occured when the temperature increases "on account of the feed" were

(a) High in the #1/#2 position

(b) High in the gas discharge temperature position

(c) Low in the #3/4 position

This suggests that the reactions started and proceeded rapidly. These were probably finished within the heated section and the quenching was completed upstream of the char trap. The cause of these favourable conditions, however, is not apparent from the data. In the future a more positive quenching action is planned.

APPENDIX 2

SAMPLE PREPARATION OF DSS FLASH HYDROPYROLYSIS SOLUTION

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Appendix 2
Sample Preparation of DSS Flash Hydropyrolysis Solution

Problem

In March, 1985 our group was asked to prepare samples obtained from the Flash Hydropyrolysis unit. We were to separate the organic compounds from the aqueous product produced from the aforementioned process.

Actions Taken

- A solvent was found that dissolved the organic in the mixture and two clear phases were obtained. The solvent used was dichloromethane (CH_2Cl_2 with a density of 1.3266).

- A procedure was then developed to separate these two phases.

Procedure

1) Place the weighed liquid sample from the FHP unit into a 500 ml separatory funnel.

2) Add appropriate amount of dichloromethane to sink the organic solution to the bottom of the separatory funnel so that a clear aqueous solution is left on the top as a float.

3) Discharge the organic solution through the bottom of the funnel and record the weight.

4) Discharge the aqueous solution from the top of the funnel and record the weight.

5) Store the samples are stored in airtight bottles so that the constituents of the product will be preserved for long periods of time without evaporation.

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4) Discharge the aqueous solution from the top of the funnel and record the weight.

5) Store the samples are stored in airtight bottles so that the constituents of the product will be preserved for long periods of time without evaporation.

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Note: A small amount of stable emulsion was sometimes found in the products from #1 Trap. This phase was separated from the other two and recorded separately. It was observed under microscope and the ratio of organic liquids was estimated.

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TABLE A1: TEST DATA AND CARBON BALANCE

Arranged in the Order of (Organic Liquids + Gaseous Hydrocarbons)

Test #		37	50	[redacted]	35	49	48	47	46	38	44	41	42
Reactor pressure	psi	1800	2000	1800	1800	2000	1800	1800	1800	1800	1800	1800	1800
Hydrogen feed rate	g/h	1037	1441	938	596	1532	1386	1286	1274	1050	1292	1069	1213
Coal feed rate (dry)	g/h	1034	1516	494	366	1636	1756	1548	1412	952	1276	1595	1405
Coal (dry) fed during test	g	1181	1200	355	903	1200	1200	1200	1200	1190	1196	1196	1194
Unaccounted mass	g/test	33.0	7.6	19.4	47.0	45.5	9.9	6.6	20.3	43.5	41.2	36.2	44.4
Unaccounted mass	% coal	2.8	0.6	5.5	5.2	3.8	0.8	0.6	1.7	3.7	3.4	3.0	3.7
Hydrogen / Coal ratio	g/g	1.00	0.95	1.90	1.63	0.94	0.79	0.78	0.90	1.10	1.01	0.67	0.86
Hydr. preheat, average	C	725	737	710	713	749	748	756	750	725	775	750	703
#1 furnace, average	C	775	741	775	750	743	738	744	746	725	725	750	700
#2,3,4 furnaces; steady	C	775	750	775	750	750	750	750	750	725	725	750	700
Gas discharge, average	C	675	662	657	625	663	661	654	645	635	630	662	615
Increase on account of feed	C	35	54	47	9	54	39	36	53	47	36	41	29
Reactor wall #1/#2, average	C	487	585	690	662	580	581	564	565	464	501	515	526
Increase on account of feed	C	11	13	10	9	16	10	15	11	14	10	11	14
Reactor wall #3/#4, average	C	631	580	627	611	586	583	597	594	582	576	620	565
Increase on account of feed	C	10	4	12	19	-1	9	17	-1	28	13	22	22
C in organic liquids	% C	19.8	22.2	21.3	17.0	22.5	20.5	18.9	22.1	19.4	20.8	18.5	17.4
C in gaseous HC's	% C	26.5	23.6	24.3	27.0	21.4	22.1	23.4	19.5	21.6	19.5	21.4	18.6
C in CO & CO2	% C	5.0	5.0	3.1	5.9	4.8	5.5	6.6	5.6	5.4	5.2	5.2	5.6
(C in gaseous products)	% C	31.5	28.6	27.4	32.8	26.2	27.6	29.9	25.1	27.0	24.7	26.6	24.3
C in char	% C	50.3	49.2	53.4	47.4	48.7	52.0	52.4	50.1	52.4	51.4	50.9	54.8
Carbon identified	% C	101.6	100.0	102.1	97.3	97.5	100.1	101.2	97.3	98.7	97.0	96.0	96.5
C in Org.liqu's and Gas's HC's	% C	46.3	45.8	45.6	44.0	43.9	42.6	42.3	41.6	41.0	40.4	39.9	36.1

Notes:

(1) The first lot of coal (relatively low carbon, high in ash) was used for Runs #35-38. The second lot was used for Runs #41-50 (Table 8).

(2) The coal was very finely ground for Run #36; all others were standard (Table 12).

TABLE A2: TEST DATA AND CARBON BALANCE

Arranged in the Order of Organic Liquids

Test #		49	50	46	36	44	48	37	38	47	41	42	35
Reactor pressure	psi	2000	2000	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Hydrogen feed rate	g/h	1532	1441	1274	938	1292	1386	1037	1050	1206	1069	1213	596
Coal feed rate (dry)	g/h	1636	1516	1412	494	1276	1756	1034	952	1548	1395	1405	366
Coal (dry) fed during test	g	1200	1200	1200	353	1196	1200	1181	1190	1200	1196	1194	903
Unaccounted mass	g/test	45.5	7.6	20.3	19.4	41.2	9.9	33.0	43.5	6.6	36.2	44.4	47.0
Unaccounted mass	% coal	3.8	0.6	1.7	5.5	3.4	0.8	2.8	3.7	0.6	3.0	3.7	5.2
Hydrogen / Coal ratio	g/g	0.94	0.95	0.90	1.90	1.01	0.79	1.00	1.10	0.78	0.87	0.86	1.63
Hydr. preheat, average	C	749	737	750	710	775	748	725	725	756	750	703	713
#1 furnace, average	C	743	741	746	775	725	738	775	725	744	750	700	750
#2,3,4 furnaces; steady	C	750	750	750	775	725	750	775	725	750	750	700	750
Gas discharge, average	C	663	662	645	657	630	661	675	635	654	662	615	625
Increase on account of feed	C	54	54	53	47	36	39	35	47	36	41	29	9
Reactor wall #1/#2, average	C	589	585	565	690	581	581	487	464	564	515	526	662
Increase on account of feed	C	16	13	11	10	10	10	11	14	15	11	14	9
Reactor wall #3/#4, average	C	556	580	594	627	576	583	631	582	597	620	565	611
Increase on account of feed	C	-1	4	-1	12	13	9	10	28	17	22	22	19
C in organic liquids	% C	22.5	22.2	22.1	21.3	20.8	20.5	19.8	19.4	18.9	18.5	17.4	17.0
C in gaseous HC's	% C	21.4	23.6	19.5	24.3	19.5	22.1	26.5	21.6	23.4	21.4	18.6	27.0
C in CO & CO2	% C	4.8	5.0	5.6	3.1	5.2	5.5	5.0	5.4	6.6	5.2	5.6	5.9
(C in gaseous products)	% C	26.2	28.6	25.1	27.4	24.7	27.6	31.5	27.0	29.9	26.6	24.3	32.8
C in char	% C	48.7	49.2	50.1	53.4	51.4	52.0	50.3	52.4	52.4	50.9	54.8	47.4
Carbon identified	% C	97.5	100.0	97.3	102.1	97.0	100.1	101.6	98.7	101.2	96.0	96.5	97.3
C in Org.liqu's and Gas's HC's	% C	43.9	45.8	41.6	45.6	40.4	42.6	46.3	41.0	42.3	39.9	36.1	44.0

Notes:

(1) The first lot of coal (relatively low carbon, high in ash) was used for Runs #35-38. The second lot was used for Runs #41-50 (Table 8).

(2) The coal was very finely ground for Run #36; all others were standard (Table 12).

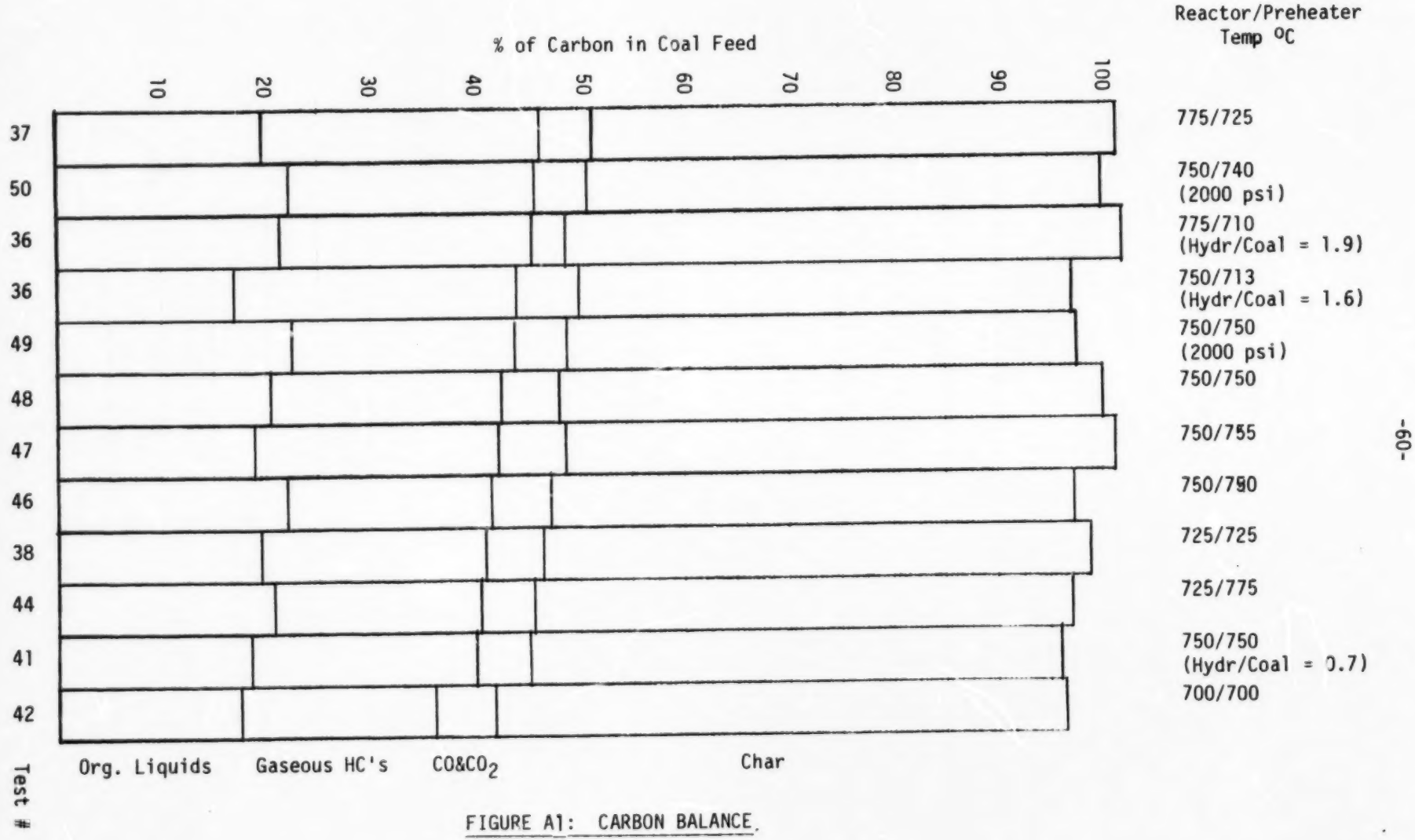

FIGURE A1: CARBON BALANCE

Arranged in the Order of (Organic Liquids + Gaseous HC's)

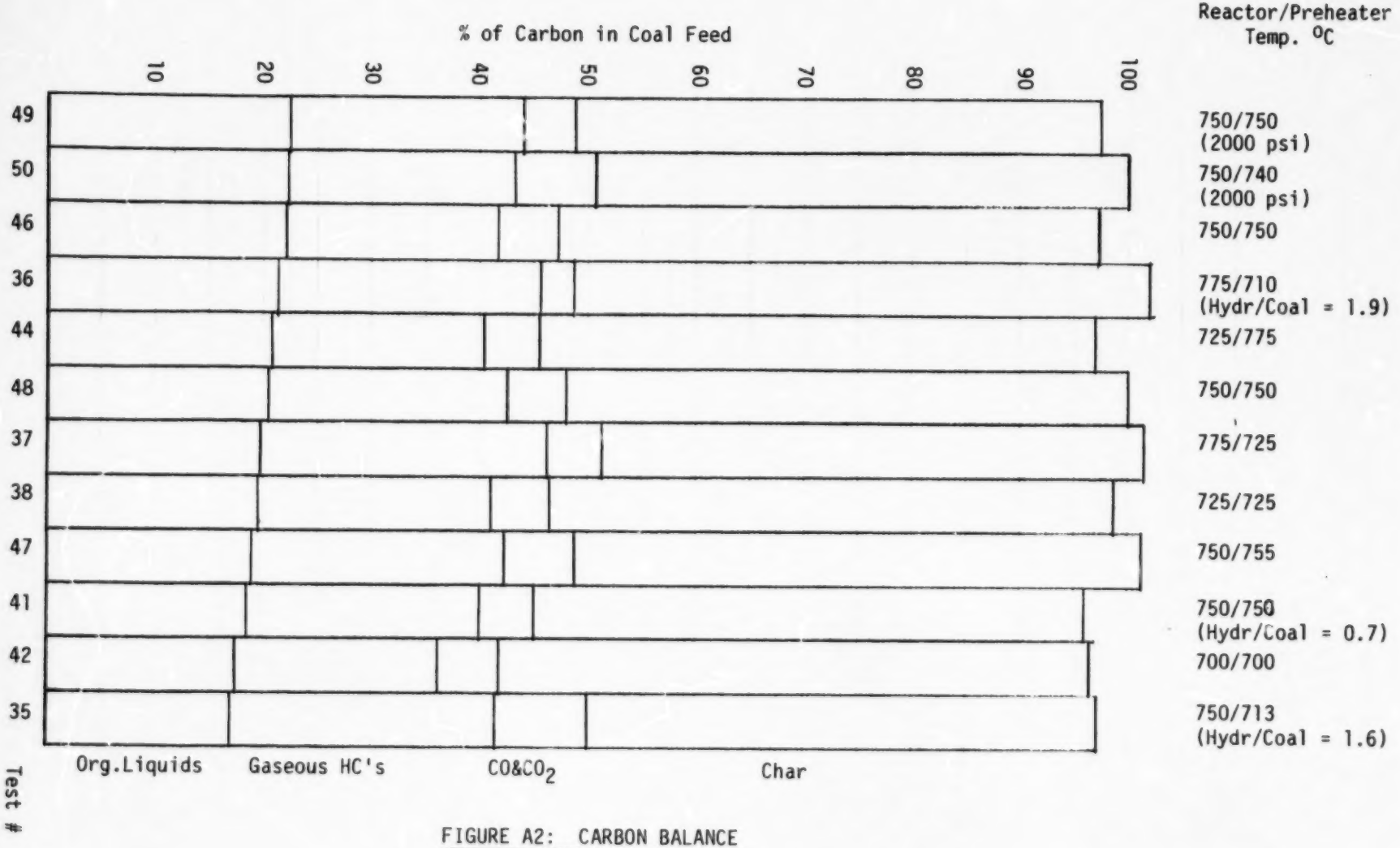

FIGURE A2: CARBON BALANCE

Arranged in the Order of Organic Liquids

APPENDIX 2

SAMPLE PREPARATION OF DSS FLASH HYDROPYROLYSIS SOLUTION

Appendix 2
Sample Preparation of DSS Flash Hydropyrolysis Solution

Problem

In March, 1985 our group was asked to prepare samples obtained from the Flash Hydropyrolysis unit. We were to separate the organic compounds from the aqueous product produced from the aforementioned process.

Actions Taken

- A solvent was found that dissolved the organic in the mixture and two clear phases were obtained. The solvent used was dichloromethane (CH_2Cl_2 with a density of 1.3266).

- A procedure was then developed to separate these two phases.

Procedure

1) Place the weighed liquid sample from the FHP unit into a 500 ml separatory funnel.

2) Add appropriate amount of dichloromethane to sink the organic solution to the bottom of the separatory funnel so that a clear aqueous solution is left on the top as a float.

3) Discharge the organic solution through the bottom of the funnel and record the weight.

4) Discharge the aqueous solution from the top of the funnel and record the weight.

5) Store the samples are stored in airtight bottles so that the constituents of the product will be preserved for long periods of time without evaporation.

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Note: A small amount of stable emulsion was sometimes found in the products from #1 Trap. This phase was separated from the other two and recorded separately. It was observed under microscope and the ratio of organic liquids was estimated.

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